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GEORGE C. LLOYD

SECRETARY



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1925

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PREFACE.

THE present volume of the *Journal of the Iron and Steel Institute* contains eighteen papers presented at the Autumn Meeting held in Birmingham in September 1925, with the discussion and correspondence thereon. In addition to these eighteen papers, a note by R. S. Johnston (Bureau of Standards, Washington) on "Strain Detection in Mild Steel by Wash Coating" is included. This note forms a further contribution to the discussion on the paper by Messrs. T. H. Turner and J. D. Jevons on "Detection of Strain in Mild Steels," published in the last volume of the *Journal*. A report by A. L. Curtis on an investigation on "Steel Moulding Sands and their Behaviour under High Temperatures," carried out with the aid of a grant from the Carnegie Research Fund, was also read and discussed at the Birmingham Meeting. The report itself has been printed in Vol. XIV. of the *Carnegie Scholarship Memoirs* (1925), but the discussion and correspondence thereon is contained in this volume of the *Journal*.

A report of the visits and excursions to works and other places of interest which were made during the Meeting is also appended, and Section I. concludes with the usual obituary notices of members deceased during the previous half year.

In Section II. will be found the usual notes on the progress of the iron and steel industries at home and abroad, with a bibliography of the more important books published during the past six months, followed by a list of the British Standardised Steel Samples.

28 VICTORIA STREET, LONDON, S.W. 1.

December 31, 1925.

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THE
IRON AND STEEL INSTITUTE.

SECTION I.
MINUTES OF PROCEEDINGS.

BIRMINGHAM MEETING.

THE AUTUMN MEETING of the IRON AND STEEL INSTITUTE was held at the University, Edmund Street, Birmingham, on Wednesday and Thursday, September 9 and 10, 1925, the President, Sir FREDERICK MILLS, Bart., D.L., occupying the Chair.

FIRST DAY (*Wednesday, September 9*).

WELCOME TO THE INSTITUTE.

THE LORD MAYOR OF BIRMINGHAM (Alderman Percival Bower, J.P.) said he desired in the first place, both personally and on behalf of his fellow-citizens, to extend to the members a very hearty and cordial welcome to the City of Birmingham. It was particularly fitting that the Institute should come to Birmingham, a city which had a peculiar affinity with the purposes for which the Institute functioned, for iron and steel had played a not unimportant part in the growth and prosperity of Birmingham.

The trade reputation of the city had been steadily built up during a period longer than the municipal history of Birmingham, and its commercial activities embraced almost everything necessary for the conduct of industry and the maintenance of our material civilisation. In the city of a thousand trades there were, on the one hand, heavy engineering works, and on the other the lightest forms of jewellery, and between those extremes there was a wide range of metallurgical industries which were, perhaps, difficult to classify, owing to the varied metals employed and the complex form in which they eventually reached the consumer. Some of the finest machinery now being turned out in Great Britain had its origin in the district of which Birmingham was the centre. In common with other large manufacturing and industrial areas, the Birmingham district had been subjected to a severe strain since the war. The part which the Iron and Steel Institute could play in assisting to secure that trade rehabilitation which was so necessary to the well-being of the nation was indeed important. But great as was that part there remained much more to be done. The nation was faced with perplexing difficulties. Those difficulties were not insurmountable, but to surmount them it was necessary to cultivate a universal desire to do so. Difficulties would not be overcome by merely aggravating them and refusing to find accommodation on points of difference. One found a disposition to play the individual game, rather than team work actuated by a genuine desire for the good of the community as a whole. It was necessary to realise that the very fact of insisting on certain rights brought with it the acceptance of responsibilities. The time had gone by when any member of society could be allowed to play his own hand regardless of its consequences to the remainder of those who constituted the community, and the sooner the principle that no one had a right to take out more than he was prepared to put in for the general welfare was accepted, the sooner should we obtain a correction of many of the difficulties confronting the nation. The functions of the Institute could, did, and would continue to assist. The age had been left behind when people could live in watertight compartments. The aim of scientific research and practical experience in great industries should be to disclose all methods whereby industry could be assisted. There was no royal road

to a solution of the national difficulties. The nation had to work out its own salvation commercially and industrially, and if the soul-destroying process in operation at the present time was to be stopped, steps must be taken to ensure the restoration of trade on lines that would lead to the complete reabsorption of the unemployed in the industries of the country. It was because he felt the efforts of the Institute were directed towards that end that Birmingham welcomed the Institute, and trusted that the meeting would be an unqualified success.

The PRESIDENT, on behalf of the members, thanked the Lord Mayor for the very cordial welcome he had extended to them to the City of Birmingham. If he did not dwell for any length of time on the deep and very appropriate remarks his Lordship had made it was not for want of appreciation of them or of the welcome that had been extended, but rather with an eye to the lengthy programme that was before them. The Lord Mayor was correct in saying that Birmingham was a most appropriate place in which to hold a meeting of the Iron and Steel Institute. It was the home of Dudley; of Andrew Yarranton (a name almost forgotten in the iron and steel trade, but that of a man who told people in the seventeenth century how to beat the Dutch without fighting, as would be found in an obscure little pamphlet in the Library of the Iron and Steel Institute, which was particularly interesting reading at the present time); of Boulton and of Watt. Nearly all the men who went to Shropshire and from there drifted into South Wales came from the Birmingham district, which was the home of the iron and steel industry as the world understood it to-day. It was therefore peculiarly appropriate that the members should visit Birmingham for the purpose of continuing their studies in the art. He did not wish to mention a great number of names, but he would like to refer to that of their most recently elected Member of Council, Professor Turner, who might or might not be a native of Birmingham, but at all events he was so closely associated with it that he was to be regarded as a Birmingham man. At its last meeting held in London the Institute had conferred upon Professor Turner the highest honour that it was in its power to bestow, namely, that of the Bessemer Gold Medal. It was said that a prophet

was not without honour save in his own country, and he never could understand how it was that he was not permitted to address Professor Turner as Dr. Turner. He presumed the Lord Mayor had a seat on the Council of the University, and he hoped his Lordship would not mind him giving him a plain hint. He again thanked his Lordship for the cordial welcome that he had extended to the members.

The Minutes of the last Annual Meeting were taken as read and confirmed.

SCRUTINEERS.

Mr. E. B. CHRISTMAS (London) and Mr. A. P. HAGUE (Sheffield) were appointed scrutineers of the ballot for the election of new members, and on completion of their scrutiny they announced that the following twenty candidates for membership and three candidates for associateship had been duly elected :

MEMBERS.

NAME.	ADDRESS.	PROPOSERS.
Ankarerona, <i>Konter-</i> <i>amiral</i> Sten Johan Theodor	Kommendörsgatan 2, Stockholm	Sir F. Mills, Bart., A. Hammarberg, A. C. P. Sjögren.
Caspersson, Oskar Fredrik	Banérgatan 51, Stock- holm	Sir F. Mills, Bart., A. Hammarberg, A. C. P. Sjögren.
Cornelius, Gustaf.	Hamngatan 1A, Stock- holm	Sir F. Mills, Bart., A. Hammarberg, A. C. P. Sjögren.
Cowan, Roysel John	National Malleable & Steel Castings Co., Toledo, Ohio, U.S.A.	H. A. Schwartz, J. V. Emmons, W. F. Abel.
Davies, Joseph Leslie Gladstone	3 Heathfield, Swansea	M. L. Simpson, J. S. Hollings, H. L. Davies.
Emerson, William Ralph, B.Sc.	54 Penn Road, Wolver- hampton	T. Turner, A. Pool, P. J. Adams.
Hale, Reginald Wood	The Woodlands, West Bromwich	H. B. Jacks, B. A. Holland.
Harriss, Richard Henry, M.I.Mech.E.	P.O. Box 5867, Johannes- burg, South Africa.	N. P. P. Sandberg, O. F. A. Sandberg, J. Waite.
Holden, John William, B.Met.	94 Melbourne Road, Stocksbridge	T. Swinden, G. R. Bol- sover, H. Bell.

NAME.	ADDRESS.	PROPOSERS.
Holmes, Alvin William	1301, S. Ebright Street, Muncie, Indiana, U.S.A.	E. G. Mahin, G. F. Comstock, H. C. Boynton.
Jones, Harold Shaw	The Willows, Brierley Hill, Staffordshire	G. Hatton, C.B.E., J. W. Trowsdale, W. H. B. Hatton.
Jones, Richard Morgan	2 Belvoir Road, Allerton, Liverpool	R. H. Smith, H. Moore, R. H. Greaves.
Magroni, <i>Ing.</i> Antonio	Terni, Italy	H. Shillitoe, A. Alberti, S. Whitmore.
Muir, William Robertson, B.Sc.	36 Garturk Street, Crosshill, Glasgow	J. H. Andrew, R. S. Wilson, D. J. Pinkerton.
Riley, John, M.Sc., Assoc.M.I.Mech.E.	3 Glen Road, Off Lees Road, Oldham	R. Taylor, N. P. Bedson, J. S. G. Primrose.
Scholes, John	"Lea Hurst," Consett, Co. Durham	E. J. George, Wybert Firth, T. W. Hand.
Schuster, Leonard Walton, M.A. (Cantab.)	British Engine, Boiler and Electrical Insurance Co., Ltd., 24 Fennel Street, Manchester	F. H. Bullock, F. C. Thompson, W. E. W. Millington.
Vanick, James Sebold, B.S.	International Nickel Co., Bayonne, N.J., U.S.A.	P. D. Merica, G. K. Burgess, H. M. Boylston.
Wesson, Alfred John	Moxley, Wednesbury	F. Scarf, J. Payton, H. B. Jacks.
Williams, Sidney David	86 Park Place East, Midland, Pa., U.S.A.	J. A. Mathews, G. B. Waterhouse, B. Stoughton.
ASSOCIATES.		
Cocquerel, Cecil A. Noël	56 St. Gabriel's Road, London, N.W. 2	H. M. Jenks, J. C. Agius, Sir A. Balfour.
Knoebel, Irvin George	403 South 11th Street, Belleville, Ill., U.S.A.	G. K. Burgess, D. A. Lyon, C. Y. Clayton.
Sambasivan, S.	H6/191 Jamshedpur, <i>via</i> Tatanagar, B.N.R., India	J. J. Ghandy, T. G. Arnold, G. Grant.

The following papers were then read :

HENNING FLODIN (Stockholm), "A New Direct Process for the Manufacture of Steel."

W. R. MARTIN (Chicago), "The Davis Steel Wheel and its Manufacture in England."

A. L. CURTIS (Chatteris, Cambridge), "Steel Moulding Sands and their Behaviour under High Temperatures."

[This paper will be found printed in the "Carnegie Scholarship Memoirs," 1925, vol. xiv. pp. 1-89.]

SECOND DAY (*Thursday, September 10*).

On the morning of Thursday, September 10, the PRESIDENT said his first duty was to announce that Sir Peter Rylands had been kind enough to undertake to fill the office of President when he (Sir Frederick) vacated the Chair. The present was not the occasion to give the members any details of Sir Peter's work on behalf of the Institute, but he was well known in the industry, and, he was sure, would make a most acceptable President to the members. He also had the pleasure to inform the members that the Council at their meeting just concluded had elected Mr. Arthur Dorman a Member of Council, to fill the vacancy due to the election of Professor J. O. Arnold as an Honorary Vice-President.

The SECRETARY announced, in accordance with Rule 10, that the following Vice-Presidents and Members of Council would be due to retire in rotation at the Annual Meeting in 1926: *Vice-Presidents*: Lord Airedale, Mr. Benjamin Talbot, and Mr. William R. Lysaght. *Members of Council*: Professor Thomas Turner, Mr. Ernest H. Saniter, Mr. John Craig, the Hon. R. D. Kitson, and Professor H. C. H. Carpenter.

All those members were eligible for re-election at the Annual Meeting. Other candidates might be nominated by members for election up to one month previous to the Annual Meeting.

The following papers were then read:

- J. L. KEENAN (the Tata Iron and Steel Company, Limited, Jamshedpur, India), "Notes on Blast-Furnace Practice in India, with Special Reference to Economy in Coke Consumption."
- C. A. EDWARDS and L. B. PFEIL (Swansea), "The Tensile Properties of Single Iron Crystals and the Influence of Crystal Size upon the Tensile Properties of Iron."
- CONSTANCE F. ELAM (London), "The Orientation of Crystals produced by Heating Strained Iron."
- R. H. GREAVES and J. A. JONES (Woolwich Arsenal, Research Department), "The Effect of Temperature on the Behaviour of Iron and Steel in the Notched-Bar Impact Test."

J. NEWTON FRIEND and W. E. THORNEYCROFT (Birmingham), "Ancient Iron from Richborough and Folkestone."

D. F. CAMPBELL (London), "High-Frequency Induction Furnaces."

The following papers were also presented, and discussion by correspondence was invited thereon :

J. H. ANDREW and R. HIGGINS (Glasgow University), "The Dilatation of Cast Irons during Repeated Heating and Cooling."

M. L. BECKER (Manchester University), "Equilibrium at High Temperatures in the Iron-Carbon-Silicon System."

E. D. CAMPBELL and J. F. ROSS (Ann Arbor, Mich., U.S.A.), "The Chromium-Iron Equilibrium in Carbides Recovered from Annealed 2.23 per Cent. Chrome Steels."

L. GRENET (Paris), "Notes on the Iron-Nickel and Iron-Cobalt Equilibrium Diagrams."

H. KAMURA (Tobata, Japan), "Reduction of Iron Ores by Hydrogen."

J. A. MATHEWS (New York), "Retained Austenite."

J. H. PARTRIDGE (Birmingham University), "The Magnetic and Electrical Properties of Cast Iron."

A. SAUVEUR and V. N. KRIVOBOK (Harvard University), "Dendritic Segregation in Iron-Carbon Alloys."

A. SAUVEUR and D. C. LEE (Harvard University), "The Influence of Strain and of Heat on the Hardness of Iron and Steel."

On the motion of the PRESIDENT a hearty vote of thanks was accorded to the authors of those papers, which would in due course be published in the Journal, with any correspondence thereon.

The PRESIDENT said that it now only remained for him to move a cordial vote of thanks to the Senate and Council of the University for the use of the rooms in the University for the purposes of the meeting.

The PRESIDENT also moved that the thanks of the Council and Members be accorded to the Lord Mayor of Birmingham and the Lady Mayoress for their hospitable welcome and reception ; to Mr. George Hatton, C.B.E., Chairman of the Reception Committee ; to Professor Thomas Turner, M.Sc., Dean of the Faculty of Science of the Birmingham University, Vice-President of the Reception Committee ; to Mr. Joseph Payton, Hon. Treasurer ;

and to Mr. H. B. JACKS, Hon. Secretary, and all the other members of the Local Reception Committee for the excellent arrangements so admirably planned and successfully carried out for the comfort, pleasure, and convenience of the members during the meeting. Also to Sir Gilbert Barling, Bart., C.B.E., Vice-Chancellor of the University of Birmingham, and Miss Barling ; to Principal C. Grant Robertson, C.V.O., M.A. ; and to Professor Thomas Turner, M.Sc., Dean of the Faculty of Science, for their kind reception and entertainment of the visitors at the University. He also expressed on behalf of the members the warm thanks of the Institute to the directors, managers, and officials of the various firms who had so kindly thrown open their establishments for the inspection of the members, and for the cordial hospitality which had been extended to the visitors. [The names of these firms are recorded in the report on the visits and excursions to works, which will be found on p. 353 of this volume.]

The resolutions were carried by acclamation.

Sir ROBERT HADFIELD, Bart. (Past-President), thought that before the proceedings terminated it would be the desire of the members that a very hearty vote of thanks should be passed to the President for the admirable manner in which he had presided over the proceedings. When the Institute last visited Birmingham, in 1895, it had a very able President in Sir David Dale, who did so much good in connection with industrial matters. No one could better have filled the important post of President during the present visit to Birmingham than Sir Frederick Mills, to whom the members were deeply indebted for all the work he had done. He was sure the members would join with him in according a most hearty vote of thanks to the President for presiding in such an admirable manner.

The resolution of thanks was carried by acclamation.

The PRESIDENT thanked the members for the cordial way in which they had given effect to the kind remarks of Sir Robert Hadfield, and the meeting then terminated.

Iron and Steel Institute.

A NEW DIRECT PROCESS FOR THE MANUFACTURE OF STEEL.

By HENNING FLODIN (STOCKHOLM).

THE following paper describes a series of experiments in the direct smelting of ore by electric means, carried out at the Electro-Chemical Section of the Royal Technical High School at Stockholm during the years 1923-25. It may be mentioned that the Electro-Chemical Section of the above-mentioned establishment, the principal of which is Professor Wilhelm Palmér, is equipped with a special electro-metallurgical laboratory, open at a nominal cost to qualified inventors, so that they may elaborate their ideas to the benefit of the industry by carrying out experiments on a sufficiently large scale to be of practical and scientific value.

The object of these trials was to ascertain whether malleable iron and steel can be extracted direct and continuously from iron ore, at the same time reducing the percentage of phosphorus and sulphur in the metal below that of the ore and coal. An electric furnace was specially constructed for the purpose, working with a load of about 30 kilowatts.

A few trials alone sufficed to establish that iron with carbon from 0.02 per cent. and upwards could be produced without difficulty. In order to prove that this was not merely a chance result from a small number of smeltings, sixty-five such trial reductions were made in a furnace of the particular construction mentioned, the results of which fully bore out that the method pursued was on the right lines. The effects were so encouraging that, on the initiative of Mr. G. Cornelius and Mr. A. Hammarberg of Stockholm, it was decided to test the process thoroughly on a reasonably large industrial scale at the ironworks at Hagfors, Sweden. An electric furnace with a load of 250 to 300 kilowatts was used, and up to the middle of July 1925 114 tappings had been made.

Analyses made at the chemical laboratory at Hagfors showed the composition of the product to be :

Carbon	from 0.02 per cent. to 1.32 per cent.
Phosphorus	„ 0.003 „ „ 0.017 „ „
Sulphur	„ 0.009 „ „ 0.077 „ „

The following results of tests carried out by Mr. O. Caspersson, engineer, indicate the physical and mechanical properties of the iron and steel produced :

Tensile Tests.

No. of Tapping.	Yield Point. Kg./mm. ²	Tensile Breaking Strength. Kg./mm. ²	Elongation ¹ per Cent.	Reduction of Area per Cent.	Condition of Test-Piece.
19	24.3	32.4	34.0	59	As rolled.
26	22.2	32.5	30.0	64	Turned from 25 mm. square, rolled bar.
27	25.4	35.3	28.5	65	Turned from 28 mm. square, rolled bar.
41	...	40.8	29.5	63	Turned from 12 mm. round, rolled bar.
42	...	45.8	12.0	61	Wire, as rolled.
42-1	...	37.7	29.0	73	Wire, as rolled and annealed.
56	31.8	45.8	25.0	54	Turned from 28 mm. square, rolled bar.
16	36.2	47.2	24.7	43	As rolled.
60	45.8	89.8	8.5	15	Turned from 28 mm. square, rolled bar.

¹ The elongation is measured on a gauge length of ten times the diameter of the test-piece.

It may here be observed that, during one of the furnace runs at Hagfors, the author was requested to vary the proportion of carbon in several successive tappings :

<i>Required.</i>	<i>Results.</i>
(1) 0.40 per cent. carbon	0.42 per cent. carbon
(2) 0.20 „ „	0.23 „ „
(3) 0.80 „ „	0.78 „ „

Thus it was found that there was no difficulty whatever in producing iron and steel of any desired carbon percentage at successive tappings without interruption of the process, showing that the process can be controlled in the same manner and quite

as easily as the discontinuous open-hearth process. The manganese and silicon contents are controlled in the same manner as in the open-hearth process. From the heat No. 3 containing 0.78 per cent. carbon, an ingot was taken and rolled out at the Forsbacka Ironworks, Sweden, and the material was used for making chisels for pneumatic hammers, drills, and miners' sledges, mainly for the purpose of testing the material. The chisels have proved to be fully equal to those made of the firm's own Bessemer steel, and nearly as good as those made of special steel alloy for the cutting out of blanks of hard steel and chrome steel (1.40 per cent. chromium, 1.10 per cent. carbon). The drill penetrated 0.4 metre into granite in a wet borehole without regrinding, and 0.6 metre into hard sandstone bored dry. Better results cannot be obtained with the best Bessemer steel. The sledges were even superior to those made of 1A Bessemer steel.

The total radiation surface of the experimental furnace at Hagfors was 30 square metres, and when running empty the furnace took about 100 kilowatts. At a load of 300 kilowatts the furnace was therefore working with 200 effective kilowatts.

A 3000-kilowatt furnace has a radiation surface 2.3 times larger than the experimental furnace, or 70 square metres, so that the heat loss would be $2.33 \times 100 = 233$ kilowatts.

In this furnace the effective load is therefore $3000 - 233 = 2767$ kilowatts. The losses due to water-cooling in the moulds, in contact rings and refrigeration, &c., amount to 263 kilowatts, making the total loss 500 kilowatts.

The loss on current at a load of 300 kilowatts in the experimental furnace was 33.3 per cent. In the 3000-kilowatt furnace it was 16.65 per cent. The loss on transformers and lines is not included, as the measurements were taken close to the furnace. For this moderate expenditure of energy the price is not so important a factor as one would be induced to expect at the first glance.

At a load of 300 kilowatts 1 ton of iron was produced in the experimental furnace, with an expenditure of 2700 kilowatt-hours. Deducting 100 kilowatt-hours for empty running, the production thus amounted to 111 kilogrammes per hour.

The 3000-kilowatt furnace is to work with a net amount of

2500 kilowatts (3000 less 500 kilowatts loss). The production will therefore be :

$$\frac{2500 \text{ kw.-hours} \times 111 \text{ kg. per hour}}{200 \text{ kw.-hours}} = 1388 \text{ kg. per hour.}$$

The gross expenditure of energy in the furnace will thus be :

$$\frac{3000}{1.388} = 2162 \text{ kw.-hours per ton of iron.}$$

The heat content of the waste gases amounts to between 2700 and 2900 calories.

If in Scandinavia the cost of hydro-electric energy is put at 50 to 60 crowns (55 to 66 shillings) per kilowatt-year, it is evidently cheaper than steam-power. According to American statistics, the price of water-power is 15 to 25 dollars per kilowatt-year, and the cost of power from large steam-power stations is 20 to 25 dollars per year. These prices of course only hold good for a constant load by day and night. With regard to future power stations installed at a great cost to take a maximum load for some few hours per day only, the conditions are of course different.

With respect to the method itself, it is unnecessary to point out that in this direct process the previous production of pig iron is dispensed with. The process works direct on a mixture of ore and coal in a single furnace, and the product is in the form of malleable iron and steel capable of being teemed into chills or other moulds in the usual manner. The process, however, does not only work direct as "one single process," but is continuous, interruptions occurring only at the moments of tapping, when the continuous feeding in of the mixture of ore and coal ceases, to recommence immediately after the tapping is complete. The operations must, of course, be carried out in such a manner that the furnace is fed with the mixture of coal and ore in quantities corresponding to the capacity of the amount of electric energy supplied for reduction and fusion.

The reduction of the iron proceeds uninterruptedly and continuously. The metallic iron particles reduced from the ore may be compared to a fine rain continually dropping through the slag bath to the bottom of the furnace, where the molten malleable iron constantly accumulates. Practically speaking, the iron is in a fit condition at any moment for tapping in varying



FIG. 1.



FIG. 2.

Ingots made at Hagfors, Sweden.

quantities in proportion to the rate of reduction, and it is hardly to be imagined that a higher degree of continuity can be reached in any process for the production of iron.

The raw materials used at Hagfors in the experimental furnace are Swedish hæmatite ore, and both English pit coal and Swedish charcoal. No refinement in special furnaces is necessary for the removal of phosphorus and sulphur to a sufficiently low point, the process being based on the principle that in the reaction the molecules are in contact, thus facilitating the transfer of the phosphorus and sulphur to the slag. A specially low-carbon material produced by the "one single process" may perhaps meet certain requirements for electric and magnetic purposes, and the product is generally suitable for any purpose where an extremely low percentage of carbon in the iron is desired. After the thorough tests to which both the iron and steel materials produced at Hagfors have been subjected, the author is satisfied that their quality is superior both to the open-hearth and the Bessemer products. While it is true that no scientific investigations have been made into the causes which make such results possible, we are justified in assuming that the superiority of the product of this electric process is due to the relative absence of gases and the small amount of slag. The process works constantly under exclusion of air, and with a slight over-pressure in the furnace. Attention is specially directed to the low percentage of carbon (0·02), and it may confidently be expected that cheap stainless iron and steel produced by the "one single process" will soon appear on the market.

DISCUSSION.

Sir ROBERT HADFIELD, Bart.* (Past-President), in opening the discussion, said that all the members were intensely interested in any method by which iron and steel could be produced directly from ore without the intervention of the blast-furnace, and there could be no doubt there was a great future for developments of that nature. He well remembered his father obtaining some iron ore from India more than forty years ago, which he had converted by the Barff process into spongy iron, which was then remelted in the crucibles of their works at Sheffield. Some of the finest crucible steel was made from that particular ore, showing that there were great probabilities and possibilities in the use of material of that kind. If the use of the blast-furnace could be avoided there was no doubt that much purer products could be obtained. At the time to which he referred samples were sent to various authorities, and he believed that there was produced in their little furnace the nearest approach, at that time, to Wootz steel, which the members probably knew was a particularly pure form of native iron as produced in the Far East.

He desired to ask the author one or two questions in regard to the table of tests, which was very interesting, but at the same time incomplete. Results were given of certain tensile tests varying from about 32 to 89 kilogrammes per square millimetre. Naturally the question immediately arose: What were the compositions of the different steels? He thought a properly correlated table, giving the composition—carbon, silicon, sulphur, phosphorus, and any other element present—would add to the interest of the paper, because it was not easy to understand the table when it showed such a wide variation of tensile strengths without the particular compositions being given. Further, no micro-structures were given in the paper, and it was important to know whether the steel was free from intermingled slag or silicates. He had no doubt it was, but he hoped the author would see his way to add that information. In addition, the results of mechanical tests other than tensile tests—for example, shock resistance and torsion qualities—would have been useful. None of those things were mentioned, and it was impossible to think of introducing such a new steel in England unless the whole of that information was before the members to enable them to judge of its qualities. He thought that the statement in regard to the exact consumption of energy per ton of material produced was not clear, and he would like the author to state specifically the figures, just in the same manner as it was usual to state the consumption of energy for melting steel; for ordinary steel he believed it was about 600 to 700 kilowatts. During the war his firm melted in electric furnaces over 100,000 tons of steel drillings at their works,

thus greatly avoiding the consumption of new material, and he believed the average consumption in melting those turnings amounted to about 650 kilowatts per ton of molten steel produced. The Sheffield Corporation charged from 0.6d. to 0.7d. per unit for electricity, and assuming for the moment that steels were made in Sheffield by the method described in the paper, he made the cost work out, according to the figures given, at something like £2 per ton. He was not quite sure whether he was correct in that figure, so that he hoped the author would further enlighten the members on that particular point.

Some interesting pictures were given of ingots on Plate I. He would like to know whether those shown in the railroad truck were of a sound nature, or was it found necessary to add the usual solidifying elements, such as silicon or aluminium, in order to obtain soundness. It was true that Fig. 2 on the lower part of the plate showed a very sound ingot. He thought if the author could see his way to sending over to this country a collection of specimens of fractures, and also of the tensile bars of which he spoke, it would add greatly to their ability to forecast the exact future for the important development described. The metallurgical world was particularly indebted for the improvements that had come from Sweden, and for the scientific research that had been done there. Some of the earliest developments in metallurgy were made by Swedish scientists. He hoped the author would continue his experiments, with the object of producing a satisfactory material, and there could be no doubt as to the adoption of anything which would assist manufacturers here to reduce costs of production. He understood the author thought that the class of ores available in Great Britain would be very suitable for treatment by his process; in fact, he (Sir Robert Hadfield) believed the President had sent some of his own ores to Sweden from Northamptonshire to be smelted and had obtained good results.

Professor H. LOUIS (Vice-President) was afraid he approached the paper with the somewhat natural distrust of one who had had a lifelong experience of direct processes. His first experience of a direct process was the Siemens rotator method for obtaining iron direct from Northampton ore at Towcester about half a century ago, and he had had to deal with a large number of others since. He was not referring to native processes, where metals were made in a small way, as in Nigeria and India, but to those which it had been attempted to work on a metallurgical scale. Those had generally been technical successes, but commercial failures. His experience at Towcester with the Northampton ore was that excellent iron was made, but a lot of bad stuff was made too. He had no doubt whatever that, given a high-class ore, it was perfectly possible to make the best quality of steel or iron by the direct process; but although he admitted that iron could be made in that way, he was very doubtful whether money could, and after all that was a point that even the scientific

metallurgist must not overlook. Until the fifteenth or sixteenth centuries only direct processes existed; since that time their place had been taken by the indirect process, simply because it could be handled on a large scale more successfully than any direct process could be. One thing he missed in the paper was information as to details of working. For instance, what scale did they work on; what was the size and type of furnace; how many heats were worked; was it a basic-lined or an acid-lined furnace? At the remote time at which he was working at Towcester basic-lined furnaces had not been thought of, and all the work was done in acid-lined furnaces. Nevertheless, if it was of any comfort to the author he could tell him that, even working with an acid-lined furnace and with an exceedingly impure ore like Northampton ore, it was perfectly possible to produce an iron free from sulphur and phosphorus. He hoped the author would also state in his reply the composition of the ore that was being used, as that was a decidedly important point. He had considerable hope some years ago of a direct process in Sweden, due, if he was not mistaken, to Dr. Gröndal and worked at Högånäs. An iron sponge was made very successfully by the use of magnetite concentrates, obtained as very nearly pure magnetic oxide of iron, which practically eliminated the slag difficulties. He would like to know if that process was still in existence, and whether the new one was a modification of it, or an attempt to supplant it, or what was the relation of the two. He hoped the author would not resent his speaking in that mistrustful manner of a new method of which he had no actual knowledge, but, as he had previously stated, he had had a lifelong experience of direct processes, one and all of which had ended in financial failure.

Mr. D. F. CAMPBELL (London) desired to ask the author for more detailed information, as the data given in the paper were very meagre. There was no doubt that steel of excellent quality could be produced direct from ore, as it had been made fifteen or seventeen years ago in electric furnaces in California, Sweden, and France, and the part of the paper dealing with that question added little to our knowledge. He thought the one and only question which affected the members at the moment was whether 20s. worth of steel would cost 20s. or more or less to produce.

The author had adopted the dangerous assumption that losses on big furnaces would be substantially less than empirical results on small furnaces, a form of extrapolation likely to introduce serious error. From the few details supplied, it appeared that the stages in the process were very similar to the Högånäs experiment with subsequent electric melting. By the Högånäs method, which was developed seventeen or twenty years ago, an extremely pure iron was made which could be melted and cast as steel of the highest quality. Sir Robert Hadfield had referred to the question of the cost of the process in England. The author's figure of 2700 electrical units per

ton was considerably higher than the figure usual for the direct reduction of ore to pig iron, though it was true that he was not making pig iron, but steel direct. If power cost 0·9d. per unit in Sheffield, that represented about £10 per ton for power alone. 0·3d. per unit was the lowest figure at which manufacturers were likely to get power in England for the next five years, unless it was arranged otherwise as a matter of book-keeping, or blast-furnace managers were willing to give them gas for nothing. At that price, the cost of the electricity alone, to say nothing of the ore and the reducing agent, was about 67s. 0d., and consequently the process could only be considered of value for countries where power was available at very low cost, and many of those districts had features unfavourable to the establishment of steel production, which necessitated the most careful consideration.

He hoped the author in his reply would give some further information in regard to the nature of the furnace used, the exact metallurgical processes involved, and the working results over a long period, in order that it might be possible to determine the value of the process in various countries.

Mr. W. SIMONS (Member of Council) said that in view of the President's statement in his Presidential Address that he had seen the process at work and that it was successful, the members had naturally read the paper with great interest. Those who had blast-furnace plants which were somewhat obsolete were looking forward with greater pleasure to such a process than those who had spent, or were spending, a great deal of capital on their new plant. He thought, however, the latter need not be unduly alarmed, because it was evident that so far material could not be produced profitably. Mr. Campbell had mentioned a figure with which he could not quite agree. As far as he could understand the figures, the current cost something like £4 per ton; and taking account of the cost of preparing the metal and of maintaining the electrical plant necessary to produce large quantities of electricity, he did not think it could be considered that the process had come within what might be called a commercial scale for producing ordinary steel, though it might be of great value for the manufacture of special steels. In conclusion, he desired to congratulate the author on having achieved more than had hitherto been accomplished.

Mr. ERNEST F. LANG (Manchester) said that the paper introduced an old subject in a new form, and in a manner in which its brevity was only equalled by its reticence. They would hope for further details in the future. In the early part of last year he was given the opportunity of witnessing some of the experiments referred to at the Royal Technical School at Stockholm. He was furnished with a sample of the material produced, and having analysed and tested the same after forging it into a bar, he could testify to its excellent qualities. That was just prior to the experiments on a larger scale by the Uddeholm Company

at Hagfors, which also demonstrated that the process was sound in principle. The quality of the metal was all that could be expected from the use of pure materials smelted under the favourable conditions provided by the reactions in the electric furnace, and the claims of the author in that respect were therefore justified. The trials at Hagfors would doubtless serve to gauge the extent of the technical difficulties involved in carrying out the process on something like a commercial scale, and also the costs of manufacture as compared with those of the electric pig iron produced there by the Uddeholm Company. The only cost given, however, related merely to that of the power consumption, and little or nothing was mentioned concerning the manufacturing methods and costs. The cost of the electric power per kilowatt-year was taken on a reasonable basis, as the new hydro-electric power schemes in progress in the north of Sweden would provide power at a much lower cost. The same cheap electric power would, however, be available for use in conjunction with the old-established indirect processes with which the direct process had hitherto been unable to compete. He referred, in that connection, to the progress of the electric blast-furnace in Sweden, as also to the use of the electric furnace for refining and melting. It would be noted that whereas the coal mixed with the iron ore was the reducing agent, it was not the direct source of the heat required for the process. The economy of the blast-furnace principle, on the lines of which the present-day direct processes were evolved, did not form a feature of the new process. The allusion to the intimate contact of the charge materials suggested the employment of special methods of mixing involving expensive manipulation, but he did not feel at liberty to refer to that further, as the author himself was silent on the point. It was, however, clear that the new process was not free from the difficulties that beset the commercial production of iron and steel direct from the ore in other direct processes. In Howe's summary of the direct processes in his classical work, it was shown that up to 1900 out of thirty-six direct reduction processes only two had survived up to that time. Further developments since that date, assisted by metallurgical and technical progress in every direction, had given birth to the Basset and Bourcoud processes. Both those processes, to which much attention had been given since the war, owed what measure of success they had achieved to the inventors having followed the economics of the blast-furnace principle combined with the latest resources of technology to produce iron sponge, continuously and on a large scale, which in the former case was brought into a gas melting furnace, and in the other case, after compression, into an electric melting furnace. It was now long since the resources of electro-metallurgical science were first applied to the problem of the direct reduction of iron ore. It was nearly thirty years since De Laval in Sweden heated pulverised iron ore and carbon in a rotating cylinder, after which the mixture was brought into contact with a powerful electric arc; and the later experiments of Stassano,

Harmet, and Keller on similar lines, embodying the principle of the reduction of iron by carbon in an electric furnace, would be well remembered, as also the paper on the subject by Humbert and Hethey at the May meeting of the Institute in 1914.

As regards the Stassano process, full details of which were published in 1899, the ore was mixed with exactly the quantity of charcoal required for the reduction, and with lime and silica for fluxing, the whole being then mixed with tar and pressed into briquettes. Those were then charged into a furnace and submitted to the heat of an arc produced between two electrodes. The promising nature of the results, technically, led to the proposal of the establishment of a works for an annual production of 4000 tons, but further larger scale experiments at Darfo, in the North of Italy, revealed so unpromising an outlook for the process commercially that the proposal was abandoned.

Harmet's process, described by him in 1902, combined electrical reduction of the ore with reduction by coke, the product being discharged into an electric refining furnace.

A year later, Keller of Paris, at the May Meeting of the Institute, in a paper on "The Application of the Electric Furnace in Metallurgy," stated that the electric reduction of iron could only compete with the blast-furnace if the kilowatt-year did not cost more than 25s. 6d. He considered, therefore, that the process was only applicable to the conditions of cheap pure ore and cheap water power.

The experiments of Humbert and Hethey, apparently on lines similar to those pursued by the author, showed the same excellence of material, and for the same reasons, namely, freedom from gaseous impurities; and commercial possibilities were claimed for the process for the production of high-grade steel in countries possessing cheap power.

Among other inventors who had explored similar fields might be mentioned Héroult in France; Lash and Taylor in America; Stansfield in Canada; Gröndal, and other experimentalists, in Sweden.

All those attempts had, however, merely gone to establish the fact that the electric furnace could only be regarded as a valuable auxiliary to the indirect processes, *i.e.* for the production of pig iron from rich ores where fuel was dear and water power cheap, as in Sweden, or for the electric smelting and refining of steel. Under such circumstances further particulars of Mr. Flodin's process would be awaited with the greatest possible interest.

Sir WILLIAM ELLIS, G.B.E. (Past-President), remarked that the author stated on p. 10 that "there was no difficulty whatever in producing iron and steel of any desired carbon percentage at successive tappings without interruption of the process." On the other hand, at the bottom of p. 12 the statement was made that "the reduction of the iron proceeds uninterruptedly and continuously." Might he read into that "reduction of the steel" as well as "reduction of the iron"?

He found very great difficulty in reconciling the two statements because, as he read them, at any moment during the continuation of the process the iron was, practically speaking, in a fit condition for tapping. He did not see how it was possible to tap at any particular moment, because, although the fluidity or the volume of material which they wished to draw off might be sufficient, he could not see how a product could be obtained giving one particular analysis, such as was being aimed at, if it was a continuous process, unless they allowed the bath to arrive at a uniform condition before tapping off a certain proportion of its contents. He hoped the author would make that point a little clearer.

Professor C. H. DESCH (Member of Council) asked the author whether he could add to his paper an analysis of the ore that was used, particularly with reference to the presence of titanium. About three years ago experiments were made in Sheffield on the direct reduction of ore, a highly titaniferous Canadian magnetite being used, and he was struck by the excellent quality of the steel obtained. It seemed, then, that the presence of a considerable quantity of titanium in the slag in a high-temperature reduction of that kind had a very favourable effect on the steel produced. One great advantage of that process was that, though they were not using a specially constructed furnace but an ordinary Greaves-Etchells furnace, it was possible to prepare alloy steels by adding not the alloying metal itself but an oxide or a native ore, and a perfect alloy was produced in an extremely pure and satisfactory condition. The run was not carried on sufficiently long to give any very definite ideas as to the cost, but he certainly arrived at the conclusion that the process as he worked it would only be practicable where electric power was exceedingly cheap. He thought every metallurgical reader of the paper would have been struck by the point to which Sir William Ellis had referred, namely, that in the production of steel of a definite carbon content in any of the processes known to them it was necessary for a definite equilibrium to be brought about between the metal and the slag. In the continuous process, in which the metal was falling in a fine rain and being tapped off at intervals, it was not easy to see how that equilibrium could be reached. One would expect to obtain either a highly carburised iron or, using only a small proportion of carbon as the reducing agent, a low carbon iron. He could understand the control of phosphorus, sulphur, and so on, but to adjust to any given limit of carbon in a continuous process seemed to be very difficult, and he thought everyone interested in the paper would like to know what actual experience had been gained in the control of the carbon. In discussing direct processes in general, a very fundamental distinction should be made between processes carried on at a very high temperature in the molten condition, and other direct low-temperature processes yielding a sponge which had always to be remelted. The chemistry of the two types was entirely different. Some time ago he carried out experiments on a low temperature direct process which

worked very well so far as the reduction of ore went, but it could only be applied if Swedish materials were used, both the charcoal and the ore being then free from sulphur. Working with English materials, particularly with English coke as the reducing agent, it was found that the iron absorbed all the sulphur that was present. On one occasion he took out from the furnace a very fluid metal which on analysis proved to be an iron-sulphur alloy containing 1 per cent. of sulphur. That was entirely different from the chemistry of the electric furnace processes which had very great advantages where power was cheap.

Mr. C. G. CARLISLE (Sheffield) said he had listened with interest to the remarks of Dr. Desch, because he was partly responsible for the experiments Dr. Desch had just touched upon. He could not see, from the details given, how the author arrived at equilibrium at all in carrying on a continuous process, nor how he held back the reduction whilst adding his ferro-silicon and manganese. Dr. Desch's remarks on the subject of titaniferous iron ore referred to a much more difficult problem than that dealt with by the author, because the reduction of ores containing titanium oxide required a great deal more attention than the reduction of hæmatite, which the author exclusively discussed. The superiority claimed for his product seemed to be a variable quantity, since the author in one place referred to it as being equal to the Swedish Bessemer and in another as being superior. There were many upholders of the Swedish Bessemer, but as a good electrical furnace man he challenged them every time, and he thought that a process would be evolved some day that would equal, or more than equal, all the processes now in existence. He noted the absence of any attack on Swedish bar iron. If the author made iron of 0.025 per cent. carbon, why did he not offer it to the Sheffield crucible steel manufacturers as a competitive article to the Swedish bar iron? Even with equilibrium obtained between slag and metal, to get 0.02 per cent. carbon every time was a most difficult problem. One objection to the author's iron was the fact that the sulphur varied a great deal on account of the coal used, and until that was remedied the author would not be able to compete.

Mr. E. H. SANITER (Member of Council) shared Professor Louis's doubts of direct processes, with some of which he had had to deal quite lately. He would not mention them by name, as some of them were still alive, but he did not think they had a very long life before them. He desired to ask the author to describe any special plant that might be necessary to carry out his continuous process, as he presumed that therein lay the whole point of the invention.

Dr. W. H. HATFIELD (Sheffield) said that in support of the point Mr. Saniter had just raised, and as representing the technical side of the Institute, he was very much interested in the direct process, but

he confessed the paper did not contain sufficient evidence to permit the members to arrive at a judgment on the process described. The author said in effect that he had made some very good steel, but he did not state how he had made it. As had previously been said, it was a demonstrable fact that pure iron could be readily directly produced by the electric furnace. He wanted to know what the author had done which marked an improvement in technical process, because the evidence was not contained in the paper. If the author in his reply to the discussion would give a description of his plant and technical details in regard to the manufacture, British metallurgists would be able to estimate the value of the process. It was not stated whether the author desired to produce iron or steel in millions of tons, such as were produced in the large plants of the United Kingdom. From the standpoint of special steels, in which he was particularly interested, nothing but the most exceptional quality of material would do. It must be pure; it must be uncontaminated by non-metallic inclusions so far as possible, and it was hoped in time to obtain steel virtually free from such inclusions. It was very doubtful, however, if a direct process would lend itself to the manufacture of such special steels. If the author's process were matched against present standard methods he (Dr. Hatfield) ventured to suggest that his costs would compare unfavourably with the cost of producing liquid steel at the moment.

Mr. F. W. HARBORD (Vice-President) agreed with Professor Louis that direct processes, although theoretically sound, had not been able to compete commercially with the blast-furnace, and that was the crux of the whole position. Many years ago the direct production of iron in the electric furnace was investigated by him, but owing to trouble with the linings, the small output, cost of repairs, &c., it could not be made to pay.

Various improvements of late years had been made enabling furnaces of larger capacity to be used, and in view of the fact that the direct production of steel from the ore was theoretically sound, he always kept an open mind when any process based on experimental work was brought before him.

The economic use of the electric furnace depended primarily on the cost of power, and with present cost of power in Great Britain he did not see how the electric furnace could hope to compete with the blast-furnace. In Sweden, where power cost one-sixth of the price here, the position was different. There was, in England, a demand for scrap of regular composition, especially for the manufacture of special steels, and assuming they could produce in Sweden, by the process described in the paper, large quantities of pure steel at a price approximating to £3 per ton, it would be cheaper to use that in England than pig iron at to-day's prices. In that direction the production of cheap steel in countries where power was cheap for export to other countries might

have possibilities, if future experience confirmed the results given in the paper.

According to the paper, the author was working with pure Swedish hæmatite, and he would like to ask whether, working with a phosphoric ore, he could get so low as 0·03 and 0·04 per cent. phosphorus in the steel. More or less reducing conditions must exist, and it was well known how readily the phosphorus passed back from the slag into the steel under such conditions. He had been particularly interested to hear the remarks made by Dr. Desch on the subject of the treatment of titaniferous ores. Some eighteen months ago he carried out some tests on New Zealand titaniferous ores and made excellent steel, but unfortunately the same trouble arose that they did not make money.

With regard to the point raised by Sir William Ellis, the adjustment of the percentage of carbon required for different steels, he presumed that what was being made in the reduction furnace at present was dead soft steel practically carbonless, and that adjustment of the charge was done by carbonising outside the furnace. In any case he saw no difficulty in doing that, if a separate finishing and refining furnace was put up to work in conjunction with the reduction furnace, when it would be possible to tap off metal as required from the ore furnace, and adjust final composition in the finishing furnace. Those, he thought, would be the lines on which the process would be likely to develop.

The PRESIDENT, in closing the discussion, thought the members were very much indebted to the author for presenting the paper to the Institute, particularly as he had given it rather earlier than he (the author) would have preferred, which possibly accounted for some of its deficiencies. Either the author did not know all the points or he did not care to mention them. At all events he (the President) had seen the process at work at Hagfors, and he found it intensely interesting, and he did not think anybody ought lightly to say it was impossible. To his mind it all depended upon the cost of the electric current. In Norway and Sweden a kilowatt-year could be obtained for less than £2, while here the cheapest price was about £8, based upon a figure of one farthing per kilowatt-hour. If electrical engineers wanted to help the steel trade, and the direct process in particular, it was necessary for them to discover how to make electrical current cheaper than it was at the present time. If the process itself was a success, but could be used only where cheap electrical power was obtainable, then it was possible that the centre of gravity of the iron-making districts was going to change; and he thought it was necessary for our people to exercise all their ingenuity and see that it did not do so, if they desired to retain an iron and steel industry in Great Britain.

CORRESPONDENCE.

Mr. E. ADAMSON (Sheffield) wrote that the author in his paper stated that the object of his trials was to ascertain if malleable iron and steel could be extracted continuously from ore. Many papers had been published, some before the Institute, to show that the question could be answered in the affirmative, but all those papers, like Mr. Flodin's, proved that none of the direct processes were capable of producing steel on a scale which would enable them to compete with the mass production of the indirect process as at present developed.

Even with current at its cost in Scandinavia as given by the author, the price would more than equal the cost of coal at present prices in producing a ton of steel in ingot form. The necessary amount of fuel to effect reduction of ore in the electric furnace must also be added. In addition, greater care would have to be exercised in the management of electric furnaces, and more highly paid men would be required to run them. Moreover, current at the cost stated was usually available only in such out-of-the-way places as to make the cost of transit very high. Consequently, by the time the electric steel reached its markets it was considerably too high in price for ordinary purposes, and the advantage of cheap current was thus neutralised. The cost of current in this country, even on a continuous load, being double that mentioned by the author, the installation of electric furnaces would be unprofitable except for special steels which commanded a high price. Again, electric furnaces could be worked in connection with ordinary steel furnaces and produce as pure a material as that obtained by the author, and at a much lower cost.

Mr. RALPH C. V. WHITFIELD (Redcar) wrote that it required but little study of the paper to arrive at the conclusion that the author's process, as far as could be ascertained, presented no new contribution to the economic solution of the problem of producing soft iron or steel direct from the ore in one operation, and that he had largely repeated what had over and over again been performed by many others without, so far, having reached material success in devising a process which could rank with standard processes as a large-scale producer. Whilst it was comparatively easy to produce soft iron or steel direct from the ore, it must be admitted that every attempt had proved abortive when measured by the cost of production. In his (Mr. Whitfield's) opinion, much of the distrust and prejudice attaching to direct processes at the present time arose solely from the fact that many much-heralded attempts to solve the problem economically had resulted in the waste of large sums of money on schemes which, if subjected to critical examination, would have been found to be based upon an

entirely wrong conception of the chemical and physical phenomena governing the production of soft iron.

The author's process could apparently be classed with those many attempts which were based upon the heating of a mixture of ore and carbon. Unfortunately for its hope of any economic success, in its adaptation to general British conditions, it could be shown most definitely that the large amount of electrical energy, as the source of heat required for the due performance of the endothermic reactions between the solid ore and fuel, was more than sufficient to condemn the entire process in its economic aspect. In this respect it fell into line with all similar previous attempts to produce direct iron.

Whilst, incidentally, the furnace used by the author was not described, nor his method of charging or furnace operation, it was much more to be regretted that no information was given as to the process itself, beyond the bare statement that the raw materials were hæmatite ore, coal or charcoal, and an electrical energy consumption of over 2000 kilowatt-hours per ton of ingot produced. No indication was given as to the proportion of iron recovered compared with that of the original ore, but even on the figures given it was possible to make the following estimate of the cost, say, in Great Britain :

	£	s.	d.
1.33 ton hæmatite ore (say 60 per cent. iron at, say, 24s. per ton)	1	12	0
8.75 cwts. coal (say 80 per cent. available carbon at, say, 20s. per ton)	0	8	9
2162 kilowatt-hours at, say, 0.5d. per kilowatt-hour	4	10	1
	<hr/>		
	£6	10	10

When, in addition, the necessary amounts were added to cover charges for labour, interest and redemption, repairs and maintenance, &c., it was very evident that the cost of the author's direct produced ingot would very materially exceed the ingot cost of any established method, and therefore the process might be ruled out of consideration as regards its possibility of becoming a serious producer of ingot metal, except in most unusual conditions not generally met with in the iron and steel industry.

In his opinion, the true solution of the direct production problem would be found in methods of gaseous reduction, and not on the lines indicated by the author of the paper, and he considered that the Council of the Institute would perform a most valuable service if it would set up a committee of inquiry into the whole problem of direct production from the ore, because he thought an authoritative report would do much to clear the air and combat the somewhat unreasonable attitude of the iron and steel industry towards what was, after all, the logical and ideal method of production.

Iron and Steel Institute.

THE DAVIS STEEL WHEEL AND ITS MANUFACTURE IN ENGLAND.

By W. R. MARTIN (CHICAGO, U.S.A.).

THE earliest railway wheels were probably not much of a problem to those first enterprising engineers in this country to whom we owe so much for our modern system of rail transportation. Wheel loads were light and speeds were slow. As railway transportation passed beyond its experimental stage and the weight and speed of trains increased, the car wheel had to be given increasing consideration. And thus throughout the whole history of the development of the world's railways there will be found the continual endeavour to improve the strength, safety, and serviceability of the railway wheel to meet the ever increasing demand in the form of heavier and faster trains.

Briefly, there are to-day four general types of wheels in use in modern railway practice. They are—the steel-tyred wheel, comprising a tyre mounted on a centre; the chilled-iron wheel; the solid rolled steel wheel, in which the centre and tyre are rolled in one piece of the same material and of the same physical characteristics; and the Davis steel wheel. The steel-tyred wheel has many variations in the nature of the centre used, the fundamental idea being to employ a soft material, such as wrought iron or cast or rolled mild steel. In America, the use of the steel-tyred wheel under passenger cars was begun about 1870. This wheel has now largely been replaced by the Davis steel wheel and the rolled steel wheel.

The author has the privilege of bringing before the Institute an interesting development in this country in the form of the manufacture of the Davis steel wheel. He has been in England for some time acting in an advisory capacity to the firm of John Brown & Company, Limited, and this firm have now put into operation a new plant specially laid down at their Scunthorpe works for the production of these wheels. Hitherto the Davis wheel had been exclusively manufactured by the American Steel Foundries at their Granite City plant, U.S.A., since its inception and development by its inventor, Mr. J. C. Davis.

About twenty-five years ago there were practically only two kinds of car wheels in use by the railways in America—*i.e.* the steel-tyred wheel and the chilled-iron wheel. Already at that time a general tendency towards heavier weights of rolling-stock, greater capacities, together with higher speeds, had become evident. About this time Mr. J. C. Davis, of the American Steel Foundries, recognising the limitations of the physical characteristics of cast iron, even when of the best quality, conceived an entirely new type of steel car wheel. He pictured as the most desirable development a one-piece wheel which would integrally combine a hard-wearing tread or tyre with a soft and ductile centre, thereby eliminating the two-piece construction of the steel-tyred wheel. The safety advantage of a one-piece wheel is self-evident, especially where much braking is employed. His ultimate development was the Davis steel wheel as it is known to-day, with its soft and safe plate and boss, and its long-wearing tread of water-toughened manganese steel.

However, the chilled-iron wheel embodies one basically valuable principle. It is essentially based on the time-honoured one-wear idea—that is to say, with this wheel there is no periodic withdrawing of the wheel from service for reconditioning of the tread. It runs its full life on one wear and without any necessity for removal from service. Mr. Davis envisaged such a principle in steel, and how well he foresaw the needs of the future has been demonstrated in the years that have followed. He planned a tread metal of such composition and physical characteristics for resistance to abrasion that a one-wear mileage could be obtained equal to the full mileage of a heavy steel tyre, including the several reconditioning operations of the latter, thus offering the railways a wheel with many times the life of the chilled-iron wheel, yet with none of the maintenance work and expense necessary with the tyred type of steel wheel. Hitherto tyre-turning had always been accepted as a necessary and constantly recurring operation in connection with the use of steel wheels. Its elimination means an important saving and a far-reaching convenience in railway operation.

In order to achieve in a one-piece structure a differential composition in the tyre as compared with the centre portion of the wheel, centrifugal casting was employed. Obviously the pouring gate

had to be at the centre, and so arranged as to permit the higher composition metal first entering the mould to be carried out to the tyre portion of the wheel. A large number of experiments were made in determining the most desirable metallurgical features. A tyre material was required with an inherent tensile strength about equal to that of rolled steel tyres, which under special treatment would develop a much higher elastic limit and tensile strength to a given depth, thereby presenting to the rail a wearing tread possessing a high degree of toughness combined with hardness, along with sufficient ductility to resist the service stresses resulting from rolling action, hammer blows, brake block heating, slippage, &c.

The most successful combination was arrived at by utilising a high-grade commercial cast steel of relatively low-carbon content; that portion of the metal which goes to make up the tyre portion having added to it sufficient manganese to provide the strength and wear-resisting qualities so much desired. The manganese is added in the form of finely divided 80 per cent. ferro-manganese.

The problem was to incorporate a given amount of ferro-manganese with a known weight of molten metal, and to do this while the hot metal was passing from the ladle to the pouring gate of the mould. That this is now being successfully accomplished is evidenced by the fact that thousands of analyses taken around the circumference of the wheel treads have shown the variations to be entirely unimportant. Repeated accuracy in this phase of the process evidently required a definite control over the sectional area of the stream of molten mild steel—*i.e.* a control of the rate of flow of the molten steel was necessary. This was accomplished by the introduction of an intermediate pouring cup, which in itself is a very simple device, yet gives remarkably satisfactory results.

Having developed this differential composition in a one-piece structure, the next problem was the matter of suitable heat treatment. As a first operation a standard annealing treatment was evolved. After this annealing the wheels are put through the finishing operations, including the turning of the tread to contour. The tyre portion of manganese steel is then given a special water-toughening quench, in such a manner as to produce a tread metal with the particular combination of toughness, hardness,

and high tensile properties desired. This heat treatment is followed by various quality tests as part of the final inspection before the wheel is despatched for service.

In 1903 the American Steel Foundries began to accept orders from the different American railways for small quantities of Davis wheels for test purposes. For four or five years the behaviour of these small test lots was carefully followed. In 1907 and 1908 the Davis wheel began to be purchased in larger quantities for passenger, goods, locomotive tender, and engine truck services. Since that time its use has steadily extended, until to-day there are approximately a million of these wheels running. It is interesting to note that there has never been a single accident chargeable to the failure of a Davis wheel.

Those who are familiar with railway conditions in America will readily appreciate that no more abusive conditions exist under which a railway wheel could be developed and perfected. Wheel loads are very heavy ; permanent way for the most part is inferior to that in this country. Trains are heavy, and in many parts of the country severe gradients exist. Further, continuous braking is universally employed. All goods trains are fitted with air-brake equipment.

In strictly goods service so few of the early wheels applied have been removed from under the cars that no adequate idea can yet be formed as to what the actual average life of these wheels will be in this class of service. For instance, in the case of one American railway some 67,000 33-inch Davis wheels were placed under 40- and 50-ton goods stock during 1911, 1912, and 1913. To date less than 5 per cent. of these wheels have been removed from service for all causes, and this despite the relatively high annual mileage figures for rolling-stock in America. The fitting of these wheels under new rolling-stock in America is extending at such a rate that the production for the first half of the present year was approximately at the rate of three hundred wheels daily. This new stock is mostly of 40, 50, 55, and 70 ton capacity, the cars being of bogie construction and fitted with eight wheels.

The tendency of the American railways serving the great anthracite and bituminous coalfields is for coal-cars of heavier and heavier capacity, with the correspondingly greater demands in the

way of wheel service, and in this the Davis wheel is playing an increasingly important part. Coal-cars of 70-ton capacity are no longer unusual, and Davis wheels have been fitted to an appreciable number of cars of 100-ton and 120-ton capacity. A considerable percentage of the American production of these wheels goes into locomotive tender service, both passenger and goods, where admittedly the conditions for wheel service and wear are the most severe. As a matter of interest some typical applications of Davis wheels to American rolling-stock are shown in the following photographs. Slide 1 shows a 70-ton coal-car equipped with Davis wheels.¹ Slide 2 shows a typical all-steel passenger coach fitted with these wheels. Slide 3 shows Davis wheels under a 100-ton capacity coal-car. It will be observed that cars of this high capacity use a six-wheel bogie—*i.e.* twelve wheels to the car.

As previously mentioned, a new plant for the making of these wheels is now in operation at the Scunthorpe works of John Brown & Company, Limited, and in the following pages is given a description of the method of their manufacture and the special plant required.

In addition to purely manufacturing problems certain slight changes in design were found advisable. For instance, in this country the universal requirement of sprag holes in all wheels for goods stock is something unusual to the American practice. Slide 4 shows the standard type of Davis wheel developed for wagon use in this country. This wheel, it will be noted, has three 6-inch diameter sprag holes in the plate in accordance with the present standard requirements. Slide 5 shows a 42-inch Davis wheel for carriage stock. In Slide 6 is shown a standard wagon wheel for Indian broad gauge.

In the matter of design the Davis wheel possesses certain very advantageous features. In Fig. 1 (Plate II.) attention is drawn to the special corrugated design of the plate portion, and the manner in which these corrugations or waves in the plate are deepest at their junction to the hub of the wheel. This design permits of maximum strength and load-carrying capacity combined with minimum weight. It provides amply for the required lateral strength and ability to resist distortion due to side-thrust. It gives stiffness

¹ The slides referred to were shown at the meeting and are not reproduced. The full list is given on p. 37.

without extreme rigidity, and a distribution of metal which to the greatest possible extent obviates the development of shrinkage strains. The corrugations are a fundamental part of the design of all Davis wheels in the larger diameters. For small diameter wheels, such as tramway wheels and narrow gauge railway wheels, the common disc type of plate is used. Slide 8 shows a Davis tramway wheel. Slide 9 shows a Davis wheel for a narrow gauge railway.

It is to be noted that with the one-wear principle of the Davis wheel an excessively thick tyre is unnecessary, inasmuch as no provision must be made as in the case of tyres for metal for re-turning operations. Important savings in weight can be effected. For instance, in the case of a standard 20-ton wagon in this country there is a direct saving of about 8 cwts. per wagon with Davis wheels as compared to the present tyred type of wheels. It only need be mentioned that the reduction of dead and non-paying load wherever possible is one of the principles of economical transportation.

In the making of the Davis wheel, the practice is to use two half-patterns mounted in heavy roll-over plates. Considerable attention is given to the finish of patterns, so that very little hand-moulding work is required. The matter of moulding sand is under close control, only new sand being used in the facing mixtures. Slide 10 shows a general view of moulding operations. The wheel moulds are made on a jolter or bumping machine, the two half-patterns being worked alternately. Empty moulding boxes come in on the right by overhead runway and the moulds go out on the left.

A unique feature of the moulding practice is a scheme for bringing the heat to the moulds. Air heated by means of a coke fire is distributed under fan pressure to a number of moulds at once. The wheel mould being of symmetrical design lends itself very well to this scheme of drying. In Slide 11 will be seen a view of the two half-moulds; the cope or top half provides feeding heads on the rim and a large central feeding head on the boss. Upon completion of the drying, the hub core is set and the mould closed preparatory to pouring. The hub core serves a dual purpose, forming the hole which subsequently is bored out for the axle fit, and also providing a central downgate through which the steel enters the mould.



FIG. 3.—Destruction test—Davis wheel in vertical drop-test position



FIG. 2.—Davis wheel tyre section, showing typical structure of fresh fracture.



FIG. 1.—Cross-section of Davis wheel showing corrugated design.



FIG. 4.—Destruction test. Same wheel in position for horizontal drop test.

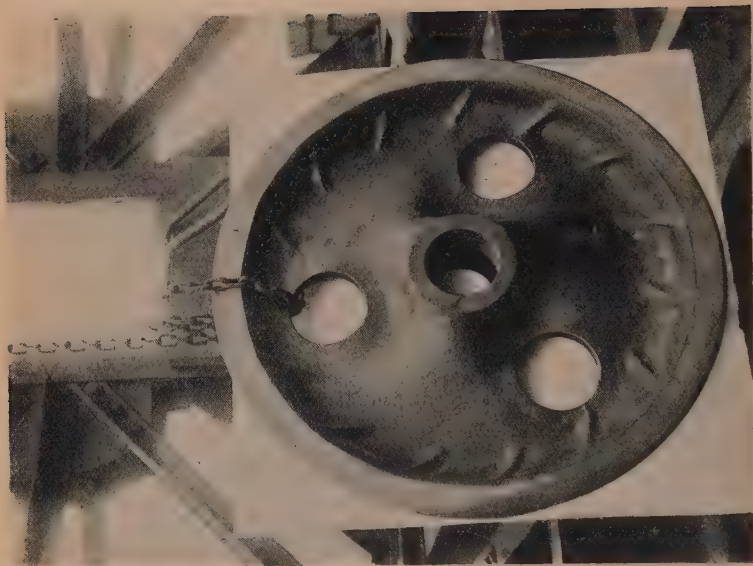


FIG. 5.—Destruction test. Same wheel after vertical test and one blow of tup from height of 10 feet, received in horizontal position.

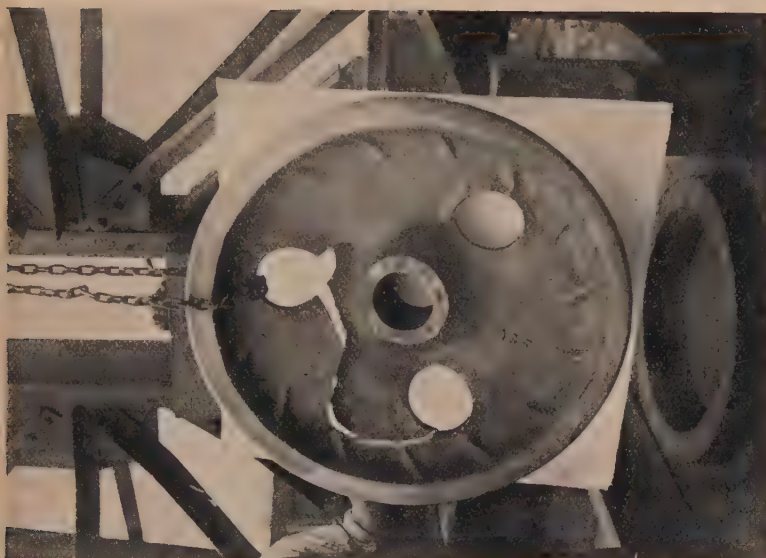


FIG. 7.—Destruction test. Same wheel after a second blow of tup from height of 20 feet, received in horizontal position.

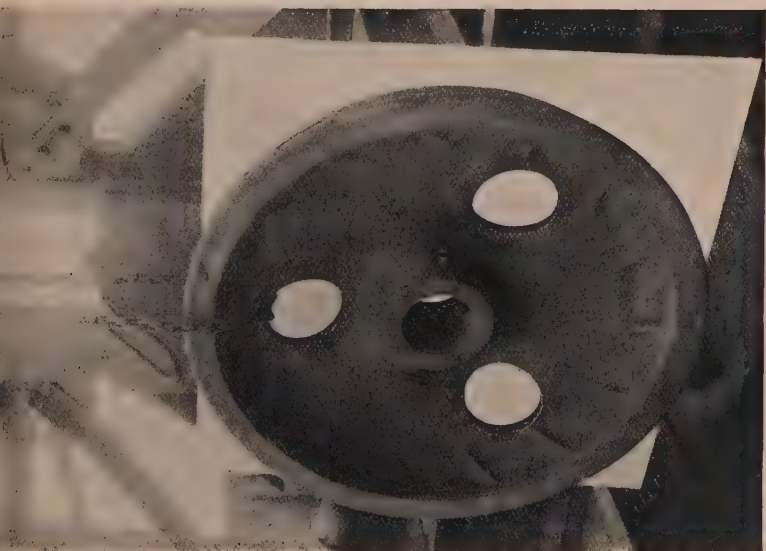


FIG. 6.—Destruction test. Same wheel after an additional blow of tup from height of 20 feet, received in horizontal position.

The closed moulds are next placed on centrifugal tables in special pouring pits. A general view of these pits may be seen in Slide 12 along with the gantry pouring crane, which carries the steel in the ladle. Steel is made by the Robert acid Bessemer process. The steel in the ladle is of ordinary mild steel composition—similar, in fact, to that in common use for the making of cast steel locomotive wheel centres. A typical analysis is as follows :

C.	Mn.	Si.	P.	S.
0.22	0.70	0.30	0.045	0.045

Slide 13 shows the mould in pouring position, along with the special pouring equipment. The intermediate cup regulates the rate of flow of the metal entering the mould independently of the varying amounts of steel in the ladle. It remains only to inject into the mild steel a predetermined quantity of ferro-manganese at a predetermined rate in order to produce an alloy of the desired composition. The ferro-manganese in finely divided form and carefully sized is carried in the appliance known as the manganese gun. The ejection of the manganese is very simply accomplished by air at a fixed pressure. The whole operation is nearly automatic, requiring only the throw of a valve by an operator. Suffice it to say that in the making of a wheel the time during which the manganese is added is controlled to one-fifth of a second.

Before the commencement of the pouring operation the mould is revolving, speeds up to 100 revolutions per minute being employed. The manganese injection is limited to the first metal entering the mould, and only to that which goes to make up the tyre section. The centrifugal action along with the symmetrical design of the mould ensures proper deposition of the manganese alloy. Completion of the ferro-manganese injection in no way interferes with the continuity of flow of the molten steel which continues to fill up the mould forming the plate and boss in mild steel. The resulting product is therefore an integral casting in the fullest sense. Centrifugal casting in this case serves a twofold purpose: first, for accomplishing the differential composition, and, secondly, for developing a fluid compression in the steel, gaining thereby a high degree of solidity.

Slide 14 shows a typical wheel section indicating the manganese composition in the tyre section, and showing the blending into the lower manganese metal of the plate and boss. It is interesting

to note that as part of the standardisation of the process here in England, John Brown & Company have made hundreds of analyses. In their early production turnings were taken at three circumferential points on the tread of many of the wheels made. Results of these analyses show a very satisfying uniformity.

After shaking out of the moulds the wheels are given an annealing treatment. The furnace used is shown in Slide 15, and is coal-fired by automatic stokers. A complete pyrometer installation is of course in use. The wheels may be seen in Slide 16, after being removed from the annealing furnace. The feeding heads will be noted both on the rim and on the bosses of the wheels.

After removal of heads, general fettling operations, &c., the wheels are rough bored. Slide 17 shows a view of the boring mill in use. The wheels then pass to the lathe, Slide 18. This is a particularly heavy machine for turning the manganese treads and is driven by a 50 horse-power motor. The whole tread contour is machined to exact dimensions, similar to tyre-turning practice. Standard contour forming tools are used for this purpose.

The machined wheels are now submitted to the water-toughening treatment. A general view of this department is shown in Slide 19. This operation needs particular explanation, inasmuch as hardness, toughness, and high tensile qualities are developed on the tread and the inside face of the flange—*i.e.* where resistance to abrasion is really needed. Quenching water is applied by means of special rings in a large number of small jets. No water comes in contact with the back side of the flange. The whole wheel is first heated to the desired temperature. During the water application there is but little loss of temperature in the plate and boss, which is allowed to cool down slowly, thus further inducing a soft condition in these portions of the wheel. It is interesting to note that there is no measurable difference in wheel diameter before and after the hardening treatment. Uniformity of treatment is assured by a definite control of the governing factors, such as temperature of the wheel before applying the water, quenching time, volume and temperature of quenching water.

Fig. 2 (Plate II.) shows a typical tyre structure. Something akin to armour-plate is developed—that is, there is a hard exterior to the desired depth, but backed by a supporting material in a softer and tougher condition. The wave-like fibrous structure, indicative

of toughness, will be noted. Flange shock tests have shown the great abundance of strength of the flange of the Davis wheel due to this differential hardness. The grain-size of the structure is extraordinarily fine as a result of the two heat treatments, and will give some understanding how it is possible to produce a wheel tread that in service literally keeps its own contour. The wearing qualities are probably due to a combination of composition, treatment, and metal density as a result of fluid compression and not to hardness in itself.

In connection with these references to hardness the matter of suitability of the Davis wheel tread for braking and the question of coefficient of adhesion may have occurred to some of you. Yet the Davis wheel is not excessively hard. Scleroscopic hardness figures range around 60 to 65. In fact, exhaustive tests have been made in the determination of the relative coefficients of adhesion of the Davis wheel, the steel-tyred wheel, and the chilled-iron wheel. These tests were made at various speeds up to 60 miles per hour, and were carried out independently by the railway engineering department of one of the large American Universities. The results of these tests showed favourably for the Davis wheel.

The tread will yield or flow a trifle under excessive loads, but not to the extent of tyres which are well known often to roll or flow over the edge of the rim. In America many Davis wheels are regularly operating under the heaviest locomotive tenders, which when fully loaded with coal and water weigh about 200,000 lbs. This load is carried on eight wheels, giving an individual wheel load of 25,000 lbs.

When sprag holes are required, as is the case in many wheels for goods service, these are machined in the plate subsequent to the hardening treatment. A single purpose machine is used for this work, as shown in Slide 21. The uniform ease with which these holes are regularly machined in the plate is further evidence of its soft nature, while the plate sections revealed are in themselves an interesting study in the solidity to be obtained by centrifugal casting.

As part of the final inspection each wheel is subjected to a ring test, consisting in a falling block of steel weighing 3 cwts. from a height of 5 feet, the wheel being supported on a rigid steel base weighing 5 tons. The facilities for this test are shown in Slide 22.

Further, each wheel must pass an individual hardness test before being passed for service. A scleroscopic hardness test is made on the tread of each wheel, as shown in Slide 23.

Finally, the wheels are exactly mated for diameter, and despatched in pairs for mounting on the same axle. A circumferential steel tape is used for this purpose, which permits extreme accuracy in the mating. This measuring of diameters may be seen in Slide 24. The wheels are now ready for finish boring and mounting on axles. Slide 25 shows some mounted wheels. These are a portion of a quantity of Davis wheels being supplied for 20-ton British wagons.

DESTRUCTION TEST.

The following is a description of a test to destruction of a standard Davis wheel for British wagons.

The wheel was first placed in a running position, resting on a 5-ton steel base on a concrete foundation. Fig. 3 (Plate II.) shows the wheel in position for test. A 1-ton tup was allowed to fall on the tread of the wheel from a height of 5 feet. The wheel was then turned around 90° and the test repeated. The wheel was unaffected by these tests.

The same wheel was then placed in a horizontal position on a circular steel ring, resting on a 5-ton steel block, the whole being on a concrete foundation. Fig. 4 (Plate III.) shows the wheel in position for this horizontal test. A 1-ton tup was then allowed to fall on the boss from a height of 10 feet. The wheel remained sound and without fracture, the boss being deflected and taking a permanent set of about $\frac{1}{4}$ inch. Fig. 5 shows the wheel after this test.

The wheel was again placed in position for the horizontal test and the 1-ton tup allowed to fall on the boss from a height of 20 feet. One small fracture was started in the plate from one sprag hole, as shown in Fig. 6 (Plate IV.).

The wheel was again placed in a horizontal position, and the 1-ton tup allowed to drop again on the boss from a height of 20 feet. Fig. 7 shows the wheel after this test. The fracture was extended further into the plate. The tenacious condition of the metal is shown as well as the inherent safety of the wheel as a structure. The wheel is still in one piece.

In conclusion, it may be said that in view of the lighter loads and more favourable conditions on this side of the Atlantic Ocean as compared with the drastic conditions, heavy trains, long gradients, and continuous braking in America, there is every reason to anticipate that the Davis wheel, with its long one-wear life and elimination of maintenance, will find far-reaching application in this and other European countries. From a safety standpoint, the combination of a soft centre and a hard tread in a one-piece wheel will readily be appreciated.

LIST OF SLIDES (NOT REPRODUCED).

- SLIDE 1.—American coal-car, capacity 70 tons, equipped with Davis wheels.
 „ 2.—American all-steel passenger carriage fitted with Davis wheels.
 „ 3.—American coal-car, capacity 100 tons, with Davis wheels.
 „ 4.—Davis wheel for British wagons.
 „ 5.—Davis wheel, carriage type.
 „ 6.—Davis broad gauge wagon wheel.
 „ 8.—Davis wheel for tramway service.
 „ 9.—Davis wheel for narrow gauge railway.
 „ 10.—General view of moulding operations.
 „ 11.—View of two half-moulds.
 „ 12.—General view of wheel pouring pits.
 „ 13.—Wheel mould in position on centrifugal table, with special pouring equipment in place.
 „ 14.—Typical wheel section showing manganese composition in tyre as compared to plate and boss.
 „ 15.—View of annealing furnace.
 „ 16.—Wheels after annealing operation.
 „ 17.—Wheel boring mill.
 „ 18.—Wheel lathe.
 „ 19.—General view of wheel heat-treating department.
 „ 21.—View of machine for machining sprag holes in plate.
 „ 22.—View of ring test.
 „ 23.—View of hardness test.
 „ 24.—Measuring and pairing wheels for diameter.
 „ 25.—Davis wheels mounted on axles.

DISCUSSION.

Sir WILLIAM ELLIS, G.B.E. (Past-President), admitted that he felt a little difficulty in speaking on the subject, for the obvious reason of the direct association of his firm with the manufacture of the Davis wheel. He considered, however, the process was one of general scientific interest as well as of metallurgical importance apart from the particular purpose to which it was being applied. It was a very fascinating and interesting application of differential analysis and differential treatment to the solution of a practical problem, and from the point of view of its scientific interest he thought it was right that it should be brought before the Institute.

Mr. E. H. SANITER (Member of Council) thought that from a metallurgical point of view it was interesting to see that a method of centrifugal casting seemed to have come into commercial use. At the meeting held at York two years ago the late Mr. McConway exhibited to the meeting some centrifugally cast discs which seemed to be excellently made and of solid material. On p. 28 the expression was used, in relation to the Davis wheel, "its long-wearing tread of water-toughened manganese steel." In this country water-toughened manganese steel was understood to mean the steel invented by Sir Robert Hadfield; but on looking at the analysis of the tread of the Davis wheel, he found it was not Sir Robert Hadfield's water-toughened manganese steel but a steel containing something under 2 per cent. of manganese, hardened intensely with water to the extent of giving something like 90 tons tensile per square inch. Under those circumstances he suggested to the author that it was unfortunate he should use the term "water-toughened manganese steel." He also thought it would add to the value of the paper if the author would include the diagram of the manganese analyses shown at the meeting.¹

Mr. RICHARD MATHER (London) said that, like Mr. Saniter, he had assumed on reading the paper that the tread was composed of a high manganese steel in the sense of the well-known Hadfield manganese steel. He also thought the inclusion of a diagram giving not merely the manganese but also the carbon contents of the different portions of the wheel would increase the value of the paper, especially if it were supplemented by a statement of the mechanical and physical properties of the tread, the hub, and the disc, so as to indicate the differences in the properties of the various portions of the wheel. It would, further, be of interest to know under what conditions of heat treatment, particularly temperature, the hardening of the tread was effected. The

¹ This diagram is shown on p. 43.

centrifugal method of casting was obviously a very pretty process, and he thought that the inventor was to be congratulated on its having reached the stage at which it could be regularly worked, despite the difficulty of controlling the rate of feeding in the powdered ferro-manganese in such a manner as to obviate a very large percentage of defective castings, in which the manganese might not have been carried far enough to give an effective tread. He thought it would prove of great value if the author could state how far the tests applied showed that the castings produced were regular in the distribution of manganese, and if he could give some idea of what kind of standard could be expected in regular practice.

Mr. F. W. HARBORD (Vice-President) said he would be glad if the author could give some information in regard to the method of adding manganese, to which reference was made in the paper. Was it added in solid or molten form? It was a little difficult to see how manganese in a solid form could be taken up and a steel of regular composition obtained during the short period of pouring.

Dr. W. H. HATFIELD (Sheffield) said that he was to some extent directly interested, and had been fortunate in being able to watch the process actually in operation for a considerable time. Furthermore, he had examined a large number of the wheels; he had cut sections of them in all directions, and had carried out detailed Brinell and hardness tests throughout such sections. He had also had an opportunity of considering the points raised by other speakers concerning the degree of variation that might be obtained when manganese was added in the way described. When the author first explained the process to him he too wondered whether the manganese did get into the right place, but there was no doubt about it, and the results were quite consistent. The whole plant worked automatically, and he was quite sure the firm would be glad to demonstrate it to any of the members. Dealing with one or two points that had been raised, so far as the mechanical tests were concerned, the test-pieces cut from the centre gave results of the same order of consistency and of the same nature as the wheel centre tests, as everyone familiar with railway wheels would understand. The tread was very uniform, running at about 380 Brinell, and the tapering off of the hardness was quite gradual and ran off in a very nice curve. In reply to Mr. Harbord's question, the manganese was added solid in a powdered form, and it was remarkable that the manganese actually did find its proper place in the wheel; obviously the big wash of mild steel which followed after the manganese had gone in ensured that. British railway practice was quite rightly very much standardised, and new introductions such as the Davis wheel would take some time, but he had every confidence that the use of the wheel would be very considerably extended. There were very real problems to be faced in connection with tyres, wheel centres, and

the fastening of tyres to the centres, and probably the Davis wheel would provide a solution to some of the difficulties which yet had to be dealt with.

Mr. C. E. STROMEYER (Manchester) desired to refer to one point on the mechanical side of the question. The reason for vibration in carriages was that when heavy masses like railway carriage wheels were jerked up and down at a high speed while passing over even slight irregularities, they picked up energy which passed into the carriage. If the rim were made very light, very little energy would be picked up and there would be very little shaking of the carriage. For instance, serious irregularities on an ordinary road did not produce as much inconvenience in a motor-car as did very slight irregularities on railway rails. Now, in the Davis wheel, the rim could be made very light and the energy picked up by it would be small, and he suggested that, in order to try the effect of lightening the rims, four Davis wheels should be fitted at one end of a Midland coach and ordinary wheels at the other end. He felt quite sure that the passengers travelling at the one end would be far more comfortable than those at the other.

Sir WILLIAM ELLIS, G.B.E. (Past-President), wished to add to his previous remarks a few words on another subject. Nothing could possibly have been more straightforward and complete than the information which had been afforded to his firm by the American metallurgists in connection with the Davis wheel. They had the advantage of the long experience gained in America, and of the very large sums of money which the Americans had spent on its production over a series of years. One member had asked a question with regard to the liability to wasters or to irregularities. Anyone embarking on the manufacture of such an article as the Davis wheel without having had previous experience would undoubtedly make irregular wheels, and would have a good many wasters, causing very serious loss. That, fortunately, had not been the case in the manufacture of the wheel in this country, not only on account of the ability of English steelmakers engaged on the process, but because they were able to start where someone else left off, a very satisfactory way of saving unnecessary expense. He desired to touch on two other advantages which the Davis wheel appeared to offer to the engineer. The heavy braking which took place on the Metropolitan and other electrical railways in London, resulting in an inevitable generation of considerable heat, greatly increased the liability for tyres to expand and come off the centres. That, he thought, was a direction in which the Davis wheel might introduce some greater degree of safety and certainty than was at present the case. That trouble was also met with in railways even with less continuous braking where heavy gradients existed and sudden braking had to be resorted to. There was some risk in placing too much dependence on the effect of contraction plus the rather insufficient

pinning for holding the tyre firmly on the centre. There, again, he thought having a one-piece wheel without any connection of that sort might be of value. The introduction of the wheel also appeared likely to be useful, especially on Indian railways, where the problems were somewhat different from those in this country. In India, tyres suffered apparently much more from rapid wear than in this country, owing to the different nature of the work. It was naturally of the highest importance that nothing should be introduced on railways without the most severe trials, tests, and examinations, and the introduction of such a wheel must necessarily be reasonably slow until railway engineers became convinced of its advantages. Very careful attention was being paid to the proving of its reliability before it was introduced into main line service in order to avoid any possible risk of accident.

CORRESPONDENCE.

Mr. A. P. HAGUE (Sheffield) wrote suggesting that the author should give the actual composition at the surface of the tread and at each subsequent $\frac{1}{8}$ inch until the soft steel in the centre was reached. A Brinell diagram showing the hardness of the wheel from the surface of the tread to the soft centre would also be of considerable interest.

In several places the tread was referred to as "of water-toughened manganese steel." Seeing that the actual manganese content did not exceed 2 per cent., that term seemed an unfortunate one. Since first described by Hadfield, the steel containing approximately 12 to 14 per cent. of manganese had been known as "manganese steel"—in view of the treatment usually given, it had also often been described as water-toughened manganese steel. The use by the author, therefore, of a similar name to describe something altogether different could only lead to confusion.

With regard to the process in general there appeared to be no doubt but that, by centrifugal casting, segregation as existing in ingots cast in the ordinary way could almost certainly be prevented. Other troubles might be introduced, but the prevention of selective freezing and its accompanying evils was worth a great deal.

Mr. W. R. MARTIN replied that the subject treated was a very broad one, and as a new undertaking in this country he felt it would be of considerable interest. In such a short paper it was obviously difficult to go into great detail in regard to the many operations involved, but he was pleased to be able to supply the further information asked for. The diagram (Fig. 8) indicated the manganese composition in the tyre as compared with the plate and hub of the wheel.

As stated in the paper, the ferro-manganese was added in finely

divided form, and uniformity of injection was very simply accomplished by air at a fixed pressure. It was simply a question of the relation of the rate of flow of the mild steel to the rate of addition of ferro-manganese to obtain an alloy of the desired composition. Uniform and complete absorption of the ferro-manganese was attained by the mixing in the downgate and hub portion of the wheel caused by the centrifugal action. The ferro-manganese was the ordinary 80 per cent. quality, containing about 5.5 per cent. carbon, the effect of the latter being to increase the carbon content of the tread by about eight points above that of the mild steel in the plate and hub. The increase in carbon was quite uniform, being directly proportional to the manganese composition and assisted in obtaining the special physical properties in the tread of the finished wheel.

Confusion of the Davis wheel tread composition with Hadfield's "high manganese" steel was particularly to be avoided. High manganese steels (10 to 14 per cent.), while resisting abrasive wear, were well known to be comparatively low in elastic limit. The requirements of wheel service made a high elastic limit eminently desirable to resist distortion and detrusion. Commercial "high manganese" steel castings would only show an average in elastic limit of 20 to 25 tons per square inch, whereas the wearing portion of the Davis wheel tread would give an average elastic limit of 60 to 70 tons per square inch. The value of high tensile qualities, and particularly of high elastic limit as a factor in reducing wheel wear, had been demonstrated beyond question and was widely recognised by railway engineers.

In Fig. 9 was shown a Brinell hardness chart of a typical Davis wheel section showing the differential hardness in the tyre section as compared with the plate and hub of the wheel. The high tensile properties in the wearing portion developed by the heat treatment operations would be noted; the temperature of the wheel at the time of quenching was approximately 1450° F. (788° C.).

As regards uniformity and regularity of the manganese practice, it might be said that, with the American experience as a foundation, the adaptation and development of the process in this country had not been a difficult problem. The simplicity of the wheel pouring operations had been demonstrated to the many railway engineers who had already visited the works at Scunthorpe.

As mentioned in the paper, many check analyses had been made at the outset. Turnings were taken at various points on the circumference of many of the first wheels made, examples of which were given in the table opposite. Points "A," "B," and "C" represent three equidistant circumferential points of the tread.

The object, of course, of the special manganese tread composition was to provide an alloy which under standardised conditions of treatment would develop the desired range of physical characteristics for strength and resistance to abrasion. Each finished wheel passed an individual routine hardness test taken at several points on the circumference,

	Point "A." Per Cent. Manganese.	Point "B." Per Cent. Manganese.	Point "C." Per Cent. Manganese.
Wheel 1 . . .	1.82	1.86	1.80
" 2 . . .	1.82	1.80	1.84
" 3 . . .	1.96	1.92	1.80
" 4 . . .	1.84	1.84	1.88

and all wheels showed a tread hardness within a very narrow range, a fact which found support in the actual experience of the British railways to whom many of those wheels had already been supplied.

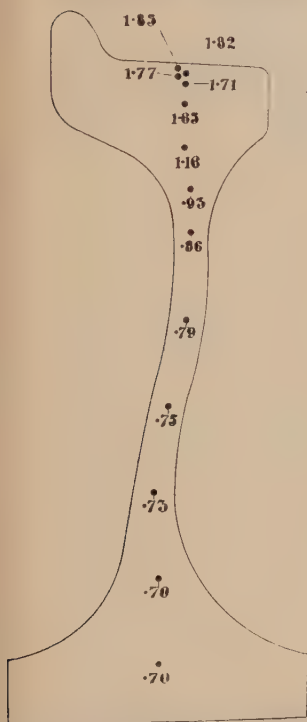


FIG. 8.—Manganese analyses showing differential composition.

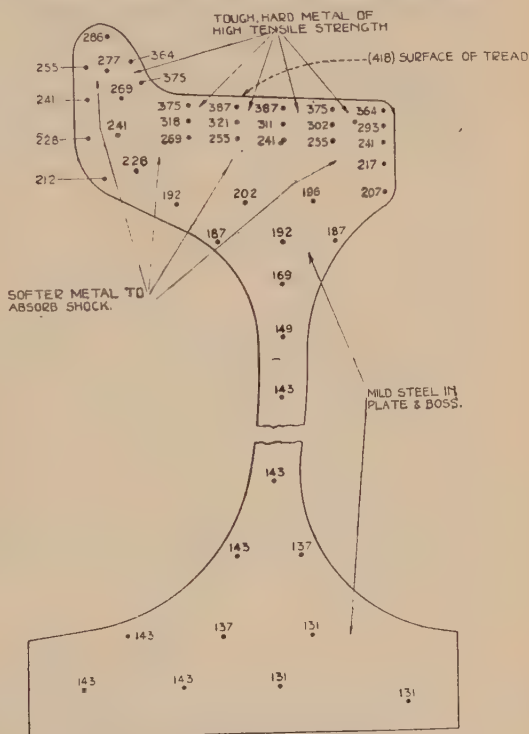


FIG. 9.—Brinell Hardness.
*Approximate Equivalents of Brinell
Numbers to Ultimate Strength.*

Brinell Numbers 418 = 92 tons per sq. in.

"	"	387 = 85	"	"
"	"	255 = 56	"	"
"	"	202 = 44	"	"
"	"	143 = 31	"	"

DAVIS STEEL WHEEL.

It was interesting to note that many hundreds of the Davis wheels already made for use here had required sprag holes. The holes were machined in the plate after the hardening treatment, and the position of the sprag holes and the ease with which they could be regularly machined at soft steel cutting speeds was satisfying evidence of the uniform softness of the plates and successful control of the differential composition.

Further, it must not be overlooked that there were approximately one million of those wheels running, and by far the best measure of reliability and uniformity was that the wheel could consistently meet the conditions for which it was intended. The destruction tests shown were intended to convey the average behaviour of the finished Davis wheel under conditions more severe than anything met with in actual service, and to demonstrate its inherent safety. The extraordinary safety record of the Davis wheel on American railways would find confirmation in the Official United States Government Records of the Interstate Commerce Commission.

Iron and Steel Institute.

NOTES ON BLAST-FURNACE PRACTICE IN INDIA, WITH SPECIAL REFERENCE TO ECONOMY IN COKE CONSUMPTION.

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It has been suggested that a short paper on modern blast-furnace practice in India would be acceptable to members of the Iron and Steel Institute. The following notes have therefore been submitted in the hope that they may prove of interest.

There are at present three modern blast-furnace plants in India. The Bengal Iron Company, the first to start operations, and the Indian Iron and Steel Company, are located near Asansol, on the East Indian Railway ; the Tata Iron and Steel Company, which started operations in 1911, is situated about one hundred and fifty miles from Calcutta on the Bengal-Nagpur Railway, two miles from the junction of the Kharkai and Subernareka rivers. The present paper is limited to describing the practice followed at the last-mentioned plant.

As both of the above-mentioned rivers practically dry up during the months of April and May, sufficient water is pumped during the year to two large basins to ensure a steady water supply.

IRON ORE.

The iron ore (hæmatite) is obtained from three mines in Mayurbhanj State : Gurumahissani (forty miles from works site), Sulaipat (forty-six miles), and Badampahar (fifty-four miles). The deposits occur in rocks of pre-Cambrian age, and are replacements of quartzites and shales. Unaltered and partially replaced quartzites and shales occur interbedded with the ores, and the source of the iron appears to be connected with a series of basic dykes which cut through the whole series. The age of replacement may be comparatively recent, geologically speaking.

Up to date none of the ore *in situ* has been worked. Only boulders and pebbles of float ore broken away from the main ore deposits have been mined. No underground work is necessary. The float forms a blanket of boulders and earth on the hill slopes, and varies from a few inches in thickness up to 18 or 20 feet.

FLUX.

Both dolomite and limestone are used, and these also are worked in deposits of pre-Cambrian age in Gangpur State (Behar and Orissa). The chief deposits now worked by the company are at Panposh and near Kansbahal, 106 and 120 miles respectively from the works site, on the main Bengal-Nagpur Railway, but a small amount of limestone is obtained from Baraduar, 250 miles from works site, also on the main Bengal-Nagpur Railway line.

COAL.

Coking coal is obtained from the Jherria coalfield (117 miles from works site) from beds of Barakar stage in the Damuda series of the Lower Gondwana system. This corresponds approximately with the Lower Permian. Gas-coals are obtained from the Raniganj stage, a little higher in the Damuda series, with a haulage of 130 to 146 miles to works site. The Raniganj coalfield lies to the east of the Jherria field, and both are served by the East Indian Railway.

PLANT AND EQUIPMENT.

The present blast-furnace plant consists of five skip-filled furnaces. "A" and "B" furnaces are the original units (see Fig. 1, p. 63). They were blown in in 1911 and 1912 respectively. They are 77 feet in height. Originally they had 12-foot hearths with a 73° 44' bosh angle, but were enlarged in 1916 to 14 feet 8 inch hearths, with 78° 14' bosh angles. "E" furnace was originally in Battelle, Alabama. This furnace was dismantled during the war and re-erected here with the same lines as "A" and "B." It was blown in first in 1919. "C" and "D" furnaces were blown in in December 1922 and January 1923 respectively. These furnaces are identical in construction,

being 89 feet $1\frac{7}{8}$ inch high. They have 17-foot hearths, 21 feet 6 inch boshes, and $79^{\circ} 5'$ bosh angles.

"A" and "B" are equipped with four Kennedy central combustion chamber two-pass stoves having a heating surface of 38,800 square feet. "C" and "D" have four side combustion two-pass stoves with 70,163 square feet of heating surface. Each stove on "C" and "D" is equipped with a waste-heat fan. All the gas for the stoves is washed in wet washers.

Raw materials are brought up a gantry and dumped into up-to-date storage bins. Practically all raw materials are brought in in bottom-dump hoppers. The ore and stone are drawn from shutes into electrically equipped lorry cars. The coke is drawn direct into skips from central bins.

The blast is supplied by two power-houses. "A," "B," and "E" furnaces are equipped with three Escher Wyss 35,000 cubic feet capacity and one 37,000 cubic feet Ingersoll Rand turbo-blowers. "C" and "D" furnaces are equipped with four 45,000 cubic feet General Electric turbo-blowers.

The boiler-plant consists of twenty-five Babcock and Wilcox combination gas and coal-fired boilers, twenty Wicks gas-fired boilers, and eight automatic coal-fired Babcock and Wilcox boilers.

"A," "B," and "E" furnaces are equipped with large cast houses with overhead cranes. These furnaces can be run into sand or ladles. "C" and "D" furnaces are equipped for ladle practice only. Any surplus metal above steel-mill requirements is poured over the pig machine, which has a capacity of 1000 tons daily. The hot metal is handled in 60-ton Pollock ladles. Slag is handled in steam dump Pollock cinder ladles and used for filling purposes. All sand-cast iron is broken hot. After cooling it is thrown over the cast-house wall on to breaking blocks and head-loaded by women into wagons.

ANALYSES AND PREPARATION OF RAW MATERIALS.

The coke-oven plant consists of 180 Coppée non-recovery ovens (now idle), a battery of 50 Koppers by-product, and three batteries of 50 ovens each of the Wilputte type, a total of 380 ovens. The production capacity is approximately 2350 tons of coke in twenty-four hours. The average coke passes through

a 4-inch ring. Four per cent. of breeze is removed from the coke bins. A fair average analysis of the coke is as follows :

Moisture.	Ash.	Vol.	S.	Fixed Carbon.
5.5	21.4	1.50	0.50	71 per cent.

All ore is crushed to pass through a 4-inch ring. The ore is practically all lumps with but a small percentage of fines, except during the rainy season, when this percentage increases slightly. The analyses over a year are as follows :

	SiO ₂ .	Fe.	P.	Mn.	Al ₂ O ₃ .
Gorumahisani .	4.25	59.59	0.066	0.50	4.04
Badampahar .	4.93	56.33	0.093	0.54	4.57
Sulaipat .	2.66	65.67	0.065	0.15	1.59

Dolomite and limestone are crushed to pass through a 5-inch ring. Limestone is used on furnaces making foundry irons and ferro-manganese, while dolomite is used on steelworks grades. The average analyses are as follows :

	Insol. Res.	Al ₂ O ₃ and Fe ₂ O ₃ .	CaO.	MgO.
Dolomite .	4.37	1.48	29.78	20.31
" A " limestone .	6.47	1.37	46.19	4.23
" B " limestone .	4.02	1.04	48.80	3.50

Manganese ore is procured from the Central Provinces. The average analysis is as follows :

Mn.	Fe.	SiO ₂ .	P.
50.6	6.4	7.2	0.09

FURNACE PRACTICE.

It is the practice at this plant to take full advantage of the stove heat. Stoves are changed every hour and fifteen minutes. The cold by-pass valves are never opened. This means that our only margin of safety is to depend on a reduction of blast volume whenever a furnace starts to go off her grade. Formerly it was the practice to carry a fair heat, say 900° F., and keep some heat in reserve. At that time the furnaces tended to work stiff, the pressure often mounting to 20 to 25 lbs. on the large furnaces,

and 16 to 20 lbs. on the smaller ones. Three hundred tons was a big daily production on "A," "B," and "E," while 475 tons was considered a big tonnage on "C" and "D."

By increasing the stove heat and paying particular attention to the rotation of filling, the pressure on all the furnaces was reduced. Within a few weeks it was only necessary occasionally to check a furnace. "A" furnace has not been checked for hanging during the past thirteen months. The others make regular pressure charts with an occasional check, which is the exception. "A" and "B" drive faster and easily produce 400 tons of basic, while "C" and "D" produce 560 tons daily. The pressure on "A" and "B" is normal at 11 lbs., on "C" and "D" at 13 to 14 lbs.

The author appends to these notes a table of operations on "C" and "D" furnaces for January and February of this year (Appendix I.). During this entire period "D" furnace made a perfect chart as far as "hanging" was concerned. It will be noted that the alumina in the slags exceeds 20 per cent., which proves that furnaces can work smoothly with high alumina slags.

There are two main features of interest concerning furnace practice in India :

1. The production of iron economically, using a soft coke of high ash content and high solubility.

2. Fuel economy resulting from changes in furnace lines.

The CO/CO₂ ratio in the gas analysis varies within small limits in producing all grades of iron. The CO content varies from 28 to 30 per cent., while the CO₂ varies from 9.5 to 11.5 per cent. In general, it has been found that the ratio 29 to 10 holds good when the furnaces are working normally, irrespective of the coke consumed per ton pig.

When "D" furnace was blown in during January 1923, gas was required to burn under the gas-fired boilers to supply power for the new mills. It was necessary to curtail the amount of gas necessary to ensure a high stove heat. Often one or two stoves were closed for hours. The result was that the ore to coke ratio was kept down to a point where the furnace would work on the low available blast temperature. The slag was kept on the "limey" side to hold the silicon down. The coke consumption was about 2700 lbs. per ton pig iron. The CO/CO₂ ratio of the gases was 29/10.

After the "C" furnace was blown in and the new coal-fired
1925—ii.

boiler-house was put into operation the stoves received their quota of gas. The blast-temperatures were immediately increased from 850° F. to 1200° F., and the ore unit was raised from 19,000 to 23,000 lbs., while at times these furnaces, "C" and "D," carried as high as 24,500 lbs. of ore during dry weather. In spite of an increase of 25 per cent. of ore the ratio of CO/CO₂ in the gases remained 29/10. The author thinks this illustrates the high solution loss that has to be contended with. Assuming for comparison only that all the oxygen in the ore is removed by CO, the figures given in Appendix II. would explain this loss.

From this table it may be seen that the carbon dropped from 2042.25 lbs. to 1687.5 lbs. per ton of iron, due to higher stove heat, more regular working, smaller slag volume, and a less basic slag. At the same time 58.2 lbs. less carbon reached the tuyeres, due to solution loss in the furnace. Any attempt to increase the ore-coke ratio beyond 24,500:15,000 leads to a cold-hearth, with accompanying high sulphur iron and with no noticeable decrease in the CO/CO₂ ratio.

FURNACE LINES.

When "A" and "B" furnaces were originally blown in they were 77 feet high (Fig. 1, p. 63). They had 12-foot hearths, 19-foot boshes. The boshes were 12 feet high. The bosh angle was 73° 44'. They produced 250 tons of basic iron per day, consuming about 2600 lbs. of coke per ton iron. From 1912 to 1916 it was possible to pick and choose the coal required for coking purposes, and it was possible to get a coking coal with about 12 per cent. ash content.

These furnaces were enlarged in 1916, the height of both remaining the same. The new hearths were 14 feet 8 inches in diameter, the boshes were 19 feet 8 inches, the angle was steepened to 78° 14', but the height of the bosh was not changed. They now produce 350 to 400 tons of basic iron per day on 2700 lbs. coke per ton pig. Since 1917 the ash content of the coking coal has increased. It is safe to say that the steepening of the bosh and the increase in diameter of the hearth would have decreased the coke consumption had the coke remained of the same quality, the hundred pounds more required to-day just about offsetting the difference in available carbon.

For some time there was much adverse criticism on the feasibility of building large modern furnaces in India, and the results obtained on our large furnaces were awaited with interest. The argument was put forward that Indian soft coke would not be suitable for these furnaces. Only a few months ago a directorate in Europe was told that furnaces of the large modern type had not proved their ability from an economic point of view. The author thinks the practice over January and February given herewith should allay the fears of even the most sceptical.

"C" and "D" are 89 feet $1\frac{7}{8}$ inch in height. The diameters of the hearths are 17 feet; the boshes are 21 feet 6 inches in diameter and 11 feet $8\frac{1}{2}$ inches high. The bosh angles are $79^{\circ} 5'$. They have a cubic content of 22,610 cubic feet, against 14,810 cubic feet, the content of the older furnaces.

When the old furnaces were enlarged there was no decrease in fuel required per ton of pig. When the new furnaces came into regular operation there was a decided decrease in fuel consumption. As the blast temperatures are practically the same and the raw materials similar, the decrease in fuel can only be due to the difference in furnace lines.

As before stated, "A" furnace works smoothly year in and year out. If it were not for the fact that "C" and "D" have proved otherwise, one would readily say that the design of "A" furnace was ideal for Indian coke. Any attempt to raise the ore unit beyond 1.3 of ore to 1 of fuel with varying sized burden units was impracticable. Still there is no difficulty in carrying a burden on the large furnaces with the ore to coke ratio 1.6 to 1. The point in question appears to be to explain why the old furnaces failed to produce iron on a lower fuel consumption than when originally built, in the face of the fuel economy resulting on still larger furnaces.

The hearths of "A" and "B" were increased in diameter, their boshes were made steeper, but their boshes were not shortened. After considering the changes from every angle the author is led to believe that the fault lies in the fact that the boshes were not shortened to make allowance for the changes in practice which must take place. In the light of recent research, new theories are being advanced every year, but furnaces are being re-lined after the model or as close as possible to the lines of the

furnace which has proved by practice that it can produce large tonnages on low fuel consumption with a given grade of raw materials.

"C" and "D" furnaces are 89 feet $1\frac{7}{8}$ inch in height. "A" and "B" furnaces are 77 feet in height. "C" and "D" furnace boshes are 11 feet $8\frac{1}{8}$ inches high, while "A" and "B" have a bosh 12 feet high. "A" and "B" have higher boshes than the larger furnaces.

	Total Contents. Cub. Ft.	Bosh Contents. Cub. Ft.	Bosh Contents Per- centage to Whole.
A and B	14,810	2840	19.2
C and D	22,610	3445	15.2
E	15,564	2840	18.25

From these figures it will be seen that the bosh contents on "C" and "D" are much smaller as compared to the whole than the same on the smaller furnaces.

The author submits a diagram of "A" and "B" and "C" and "D" furnaces (Fig. 1).

Assuming that the top of the bosh was situated at the right height for "A," "B," and "E," when they were originally built—i.e., that the descending column of solids started to contract at this point due to fusion—we will now look at the difference after the enlargement of these furnaces.

Larger hearth and tuyere areas demanded more blast to burn the larger area of coke present and to give the proper penetration to ensure smooth working. The greater blast volume lowered the zone of fusion. More stove heat was required, which in turn lowered the zone of fusion, with the result that the descending column of solids reached the top of the bosh before the proper contraction due to fusion took place. The result of this causes one of two things: first, the furnace tends to hang on high pressure; or, second, the descent of the sinking column of stock is retarded sufficiently at the top of the bosh to permit the zone of fusion to rise automatically to the top of the bosh. Both cases demand more coke, especially the second case, where the heat required to do the work on an economical basis in a given area is spread out over a larger area.

If this theory be true—the lowering of the top of the bosh to where the height of the bosh would be comparable to that of the larger furnaces—then the descending column of solids would reach the zone of fusion at the new inverted angle, immediately contracting, and holding the working zone down where it should be. It would then be found that the amount of heat formerly required would be too great for the smaller working area, with the result that the coke requirements could be greatly reduced.

The author will have an opportunity in the near future of observing the saving in fuel resulting from shorter boshes, as one of the old units is at present being relined. Although the bosh is to be shortened, all other lines will be as heretofore. Therefore any saving in fuel will be a direct result of lowering the zone of fusion, due to lowering the top of the bosh. The hearth diameters of furnaces in America were originally increased with larger production in view. The boshes were steepened to conform with the original diameters of the old mantles and that of the new hearths. Larger production resulted, also economy in fuel. The economy in fuel was, the author believes, due entirely to the fact that, as the bosh became more and more perpendicular, the top of the bosh was lowered automatically as the angle became less perceptible.

Whilst theory with regard to reduction in coke consumption, consequent upon lowering the top of the bosh and therefore the zone of fusion, must be a matter of pure conjecture, the author believes that such economy is the result of a more economical production and utilisation of carbon monoxide. Whatever the correct theory, however, the main commercial result holds—namely, that by such alteration in furnace lines the coke consumption per ton of pig iron produced has been lowered by 470 lbs., *i.e.* a reduction of 17 per cent.

A thermal balance sheet for “D” furnace is appended (Appendix III., Plate V.).

The author desires, in conclusion, to express his hearty thanks to Mr. T. W. Tutwiler and Mr. C. A. Alexander, late and present general managers at Jamshedpur, for the guidance and encouragement which they have always extended to his work. He desires further to record his hearty appreciation of the loyal co-operation of the staff—Indian, British, and American.

APPENDIX I.

Blast-Furnace Record of "C" Furnace (Tata Iron and Steel Co., January 1925).

Date.	Total Tons Iron Pro- duced.	Coke Con- sumed per Ton Iron (Lbs.).	Dolomite Con- sumed per Ton Iron (Lbs.).	Ore Mixture (per Cent.).			Blast.			Top Gas Temperature, °F.	Atmospheric Moisture, Grains per Cubic Foot.	Analysis of Iron Produced.			
				Sulaplat.	Badam- pahar and Guruma- hissani.	Blower.	Cubic Feet per Min.	Tem- perature, °F.	Pres- sure.			Si.	S.	P.	Mn.
1	551	2216	1291	25	75	3	42,000	1109	11	285	5.5	0.82	0.020	...	1.55
2	617	2069	1170	"	"	3	42,000	1124	10½	280	5.1	0.72	0.025	0.330	1.49
3	545	2284	1285	"	"	3	42,000	1184	11½	260	5.3	0.80	0.029	0.328	1.42
4	479	2483	1412	"	"	3	42,000	1174	11½	295	5.0	1.20	0.023	...	1.40
5	624	1916	1122	"	"	3	42,000	1164	11½	485	4.9	0.86	0.022	0.324	1.21
6	636	1864	1044	"	"	3	42,000	1199	12	755	4.6	0.99	0.023	0.336	1.23
7	543	2095	1218	"	"	3	42,000	1154	11½	270	4.7	1.00	0.029	0.332	1.36
8	505	2072	1158	"	"	3	42,000	1104	12	310	5.2	1.22	0.025	0.328	1.28
9	612	1878	1087	"	"	3	42,000	1029	11½	275	4.0	1.22	0.033	0.312	1.05
10	588	1937	1172	"	"	3	42,000	1044	11½	230	4.3	0.93	0.032	0.332	1.10
11	597	1954	1198	"	"	3	42,000	1044	11½	230	4.7	0.90	0.040	0.316	1.08
12	607	2012	1236	"	"	3	42,000	1109	12	255	4.8	0.66	0.046	0.326	1.06
13	618	1883	1183	"	"	3	42,000	1264	10½	390	4.3	0.71	0.041	0.324	1.10
14	522	2188	1323	"	"	3	42,000	1094	11	230	4.5	0.93	0.032	0.316	1.24
15	550	2070	1238	"	"	3	42,000	1074	11	215	4.4	0.77	0.034	0.312	1.30
16	518	2100	1249	"	"	3	35,000	1124	12	240	4.2	0.75	0.031	0.320	1.22
17	541	2171	1227	"	"	3	35,000	1164	11	340	4.0	0.81	0.030	0.324	1.28
18	482	2363	1335	"	"	3	35,000	1144	11½	275	3.9	0.75	0.042	0.336	1.37
19	617	1940	1144	"	"	3	38,000	1169	11½	260	4.1	0.76	0.033	0.332	1.32
20	541	2257	1350	"	"	3	40,000	1139	11	255	5.1	0.84	0.035	0.328	1.27
21	525	2450	1439	"	"	3	40,000	1149	10½	290	4.9	0.83	0.027	0.328	1.27
22	586	2174	1288	"	"	3	40,000	1144	10	290	4.7	0.82	0.029	...	1.49
23	610	1983	1137	"	"	3	38,000	1144	11½	345	4.3	0.76	0.027	0.326	1.35
24	557	2178	1222	"	"	3	38,000	1169	11½	350	4.2	0.91	0.028	0.332	1.28
25	569	2145	1187	"	"	3	40,000	1239	12	395	4.0	0.85	0.032	0.336	1.14
26	557	2205	1283	"	"	3	40,000	1179	11½	280	4.2	0.74	0.041	0.312	1.08
27	559	2115	1216	"	"	3	35,000	1214	12½	340	4.1	0.87	0.053	0.328	1.09
28	574	1972	1170	"	"	3	35,000	1214	11½	340	4.2	0.91	0.046	0.312	1.26
29	519	2171	1273	"	"	3	35,000	1224	11½	408	4.0	0.89	0.040	0.336	1.53
30	547	2091	1228	"	"	3	38,000	1154	12½	340	4.1	1.14	0.028	0.332	1.69
31	518	2226	1313	"	"	3	35,000	1149	12	340	3.9	0.92	0.032	0.332	1.26

Total, 17,414

Average Analysis of Materials.

	SiO ₂ .	Al ₂ O ₃ .	Fe.	Mn.	P.
Average ore analysis . . .	3.27	3.37	61.41	0.41	0.061
Average Sulaipat ore analysis	2.01	1.91	66.40	0.32	0.042

	Insoluble Residue.	Fe ₂ O ₃ . Al ₂ O ₃ .	CaO.	MgO.
Average dolomite analysis . .	3.90	0.99	30.28	20.25

	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.	Sulphur.
Average coke analysis . . .	7.6	21.5	1.31	70.02	0.57

Average blast temperature . .	1148° F.
" " pressure . . .	11½ lbs.
" top gas temperature . . .	321° F.

Materials Consumed per Ton per Month.

	Lbs.
Coke	2102
Dolomite	1172
Ore	3398

Total Materials Consumed during the Month.

	Tons.
Coke	16341.8
Ore	26414.3
Dolomite	9543.7
Scrap	278.2

Average Analysis of Products.

	Si.	S.	P.	Mn.
Average pig iron analysis	0.88	0.032	0.325	1.28

	SiO ₂ .	Al ₂ O ₃ .	CaO.	MgO.	FeO.	MnO.
Average slag analysis . .	29.21	20.59	29.52	17.04	1.57	1.25

	CO ₂ .	CO.	O ₂ .	OH ₂ .	H ₂ .
Average gas analysis . .	10.3	29.4	0.2	1.2	1.0

Average slag per ton iron 1272 lbs.

Blast-Furnace Record of "C" Furnace (Tata Iron and Steel Co., February 1925).

Date.	Total Tons Iron Produced.	Coke Consumed per Ton Iron (Lbs.).	Dolomite Consumed per Ton Iron (Lbs.).	Ore Mixture (per Cent.).			Blast.			Top Gas Temperature, F.	Atmospheric Moisture, Grains per Cubic Foot.	Analysis of Iron Produced.			
				Sulalpat.	Gurumahissani and Badampahar.	Blower.	Cubic Feet per Min.	Temperature ° F.	Pressure.			Si.	S.	P.	Mn.
1	516	1997	1161	25	75	4	38,000	1139	11½	345	...	0.65	0.037	0.320	1.53
2	511	2299	1326	"	"	4	43,000	1084	11	345	...	0.90	0.043	...	1.35
3	628	1932	1098	"	"	3	35,000	1074	11	360	...	0.66	0.047	0.318	1.13
4	533	2146	1200	"	"	4	45,000	1094	11	360	...	0.84	0.047	0.324	1.24
5	511	2242	1272	"	"	3	35,000	1089	11½	340	...	0.85	0.042	0.308	1.13
6	564	2142	1238	"	"	2	48,000	1194	12½	390	...	0.83	0.045	...	1.13
7	595	2107	1246	"	"	2	48,000	1259	12½	355	...	0.71	0.052	0.306	0.99
8	521	2241	1309	"	"	2	45,000	1294	12	350	...	0.74	0.040	0.320	1.50
9	529	2511	1475	"	"	2	48,000	1194	12½	365	...	0.72	0.040	0.328	1.27
10	536	2429	1370	"	"	2	44,000	1339	11	345	...	0.81	0.050	0.328	1.12
11	608	2147	1192	"	"	2	48,000	1234	12	430	...	0.87	0.045	...	1.31
12	523	2463	1395	"	"	2	48,000	1159	12	385	...	0.94	0.027	0.348	1.34
13	548	2312	1317	"	"	2	48,000	1089	12½	380	...	0.91	0.031	0.336	1.33
14	489	2629	1492	"	"	2	48,000	1109	12	380	...	0.97	0.027	0.332	1.46
15	564	2279	1284	"	"	2	48,000	1154	12	400	...	0.85	0.028	...	1.10
16	527	2417	1369	"	"	2	48,000	1124	12½	370	...	0.81	0.033	0.334	0.97
17	566	2236	1261	"	"	4	45,000	1124	12	385	...	0.89	0.036	0.328	1.00
18	534	2164	1242	"	"	2	48,000	1044	12	360	...	0.95	0.037	...	1.16
19	532	2325	1342	"	"	2	48,000	1044	12½	390	...	1.01	0.034	0.332	1.26
20	583	2064	1213	"	"	2	48,000	1054	12½	360	...	0.81	0.034	0.324	1.23
21	568	2089	1213	"	"	2	48,000	1109	12	365	...	0.82	0.035	...	1.17
22	594	2022	1174	"	"	2	48,000	1140	12½	265	...	0.80	0.031	0.324	1.23
23	534	2250	1279	"	"	2	48,000	1119	12	315	...	0.82	0.029	...	1.09
24	589	2064	1184	"	"	2	48,000	1039	12½	330	...	0.81	0.033	0.332	0.90
25	558	2290	1287	"	"	2	48,000	1189	12½	330	...	0.70	0.031	0.332	1.51
26	517	2433	1381	"	"	2	48,000	1104	12½	310	...	0.86	0.034	0.320	1.56
27	544	2293	1312	"	"	2	48,000	1099	12½	290	...	0.81	0.040	0.296	1.28
28	603	2016	1164	"	"	2	45,000	1084	12½	285	...	0.82	0.049	0.288	1.39

Total, 15,425

Average Analysis of Materials.

	SiO ₂ .	Al ₂ O ₃ .	Fe.	Mn.	P.
Average ore analysis . . .	2·90	3·39	60·95	0·58	0·064
Average Sulaipat ore analysis	1·70	1·39	66·80	0·30	0·097

	Insoluble Residue.	Fe ₂ O ₃ Al ₂ O ₃ .	CaO.	MgO.
Average dolomite analysis .	3·26	1·35	29·51	20·70

	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.	S.
Average coke analysis . . .	6·27	21·82	1·52	69·89	0·50

Average blast temperature . .	1134° F.
„ „ pressure . .	12 lbs.
„ top gas temperature . .	352° F.

Materials Consumed per Ton per Month.

	Lbs.
Coke	2226
Dolomite	1274
Ore	3480
Scrap	146·1 tons (during the month)
	= 21 lbs. per ton of iron made.

Total Materials Consumed during the Month.

	Tons.
Coke	15,330
Dolomite	8,773·2
Ore	23,967·5

Average Analysis of Products.

	Si.	S.	P.	Mn.
Average pig iron analysis	0·82	0·037	0·323	1·19

	SiO ₂ .	Al ₂ O ₃ .	CaO.	MgO.	FeO.	MnO.
Average slag analysis .	28·99	19·92	29·54	17·54	1·58	1·24

	CO ₂ .	CO.	O ₂ .	CH ₄ .	H ₂ .
Average gas analysis .	10·2	29·70	0·3	0·8	1·2

Average slag per ton of iron . . . 1359 lbs.

Blast-Furnace Record of "D" Furnace (Tata Iron and Steel Co., January 1925).

Date.	Total Tons Iron Produced.	Coke Consumed per Ton Iron (Lbs.).	Dolomite Consumed per Ton Iron (Lbs.).	Ore Mixture (per Cent.).		Blower.	Blast.			Top Gas Temperature.	Atmospheric Moisture, Grains per Cubic Foot.	Analysis of Iron Produced.			
				Gurumahisani.	Badam-pahar.		Cubic Feet per Min.	Temperature, ° F.	Pressure.			Sl.	S.	P.	Mn.
1	603	2105	1133	50	50	2	48,000	1287	11½	425	5.5	1.46	0.028	0.348	1.25
2	591	2067	1113	"	"	2	48,000	1292	11	420	5.1	1.29	0.039	0.332	1.22
3	533	2408	1317	"	"	2	48,000	1232	11½	455	5.3	1.33	0.033	0.344	1.09
4	630	2004	1097	"	"	2	48,000	1232	11½	425	5.0	1.14	0.035	0.348	1.26
5	601	2024	1136	"	"	2	48,000	1207	11½	415	4.9	1.10	0.032	0.332	1.20
6	672	1846	1017	"	"	2	48,000	1232	11½	450	4.6	0.80	0.038	0.344	0.97
7	589	2061	1114	"	"	2	48,000	1232	11	425	4.7	0.92	0.041	...	1.05
8	524	2250	1230	"	"	2	48,000	1227	11	465	5.2	1.22	0.028	0.348	1.07
9	603	2124	1178	"	"	2	48,000	1242	11½	440	4.0	1.22	0.032	0.332	1.25
10	604	2102	1074	"	"	2	48,000	1212	11½	470	4.3	1.06	0.036	0.328	1.32
11	521	2345	1392	"	"	2	48,000	1172	11½	455	4.7	1.17	0.041	0.340	1.34
12	596	2131	1221	"	"	2	48,000	1172	11	440	4.8	0.95	0.036	0.332	1.27
13	521	2298	1371	"	"	2	48,000	1187	11½	485	4.3	1.24	0.033	0.336	1.27
14	606	2045	1193	"	"	2	48,000	1172	11½	475	4.5	1.45	0.027	0.346	1.12
15	473	2615	1507	"	"	2	48,000	1092	11	445	4.4	1.67	0.029	...	1.17
16	546	2185	1279	"	"	2	48,000	1157	10½	435	4.2	1.44	0.032	0.324	1.21
17	571	2208	1277	"	"	2	48,000	1137	10	455	4.0	1.28	0.028	0.332	1.46
18	607	2043	1177	"	"	2	48,000	1209	10½	420	3.9	1.03	0.033	...	1.15
19	555	2309	1361	"	"	2	48,000	1037	10½	410	4.1	0.96	0.044	0.332	1.53
20	496	2448	1430	"	"	2	46,000	1122	10	430	5.1	0.95	0.039	0.336	1.10
21	501	2582	1422	"	"	2	48,000	1122	10½	430	4.9	1.02	0.030	0.352	0.88
22	608	2003	1094	"	"	2	48,000	1192	10½	445	4.7	1.29	0.028	0.340	0.73
23	544	2217	1151	"	"	2	48,000	1237	11½	435	4.3	1.41	0.026	0.348	0.71
24	579	2245	1143	"	"	2	48,000	1222	11½	480	4.2	1.39	0.021	0.328	1.01
25	570	2230	1158	"	"	2	48,000	1187	12	460	4.0	1.52	0.026	0.348	1.23
26	564	2165	1180	"	"	2	48,000	1182	12½	470	4.2	1.68	0.025	0.352	0.84
27	533	2380	1255	"	"	2	48,000	1157	12½	470	4.1	1.67	0.028	0.360	0.88
28	589	2323	1226	"	"	2	48,000	1207	11½	440	4.2	1.12	0.033	0.356	0.70
29	614	2116	1131	"	"	2	48,000	1277	11	445	4.0	1.00	0.051	0.320	0.67
30	520	2533	1387	"	"	2	48,000	1212	12	460	4.1	1.43	0.035	0.352	1.21
31	602	2167	1228	"	"	2	48,000	1252	11½	430	3.9	1.20	0.034	0.328	1.26

Total, 17,666

Average Analysis of Materials.

	SiO ₂ .	Al ₂ O ₃ .	Fe.	Mn.	P.
Average ore analysis.	3.27	3.37	61.41	0.41	0.061

	Insoluble Residue.	Fe ₂ O ₃ . Al ₂ O ₃ .	CaO.	MgO.
Average dolomite analysis	3.90	0.99	30.28	20.25

	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.	Sulphur.
Average coke analysis	7.6	21.5	1.31	70.02	0.57

Average blast temperature	.	.	1195° F.
" " pressure	.	.	11 lbs.
" top gas temperature	.	.	444° F.

Materials Consumed per Ton per Month.

	Lbs.
Coke	2200
Dolomite	1215
Ore	3622

Total Materials Consumed during the Month.

	Tons.
Coke	17,357.6
Dolomite	9,629.9
Ore	28,582.9
Scrap	360.8

Average Analysis of Products.

	Si.	S.	P.	Mn.
Average pig iron analysis	1.11	0.033	0.339	1.10

	SiO ₂ .	Al ₂ O ₃ .	CaO.	MgO.	FeO.	MnO.
Average slag analysis	28.4	21.30	28.2	18.09	1.67	1.7

	CO ₂ .	O ₂ .	CO.	CH ₄ .	H ₂ .
Average gas analysis	10.05	0.5	29.4	1.5	0.6

Average slag per ton iron . . . 1326 lbs.

Blast-Furnace Record of "D" Furnace (Tata Iron and Steel Co., February 1925).

Date.	Total Tons Iron Pro- duced.	Coke Con- sumed per Ton Iron (Lbs.).	Stone Con- sumed per Ton Iron (Lbs.).	Ore Mixture (per Cent.).		Blower.	Blast.			Top Gas Temperature. ° F.	Atmospheric Moisture, Grains per Cubic Foot.	Analysis of Iron Produced.			
				Badam- pahar.	Guruma- hissani.		Cubic Feet per Min.	Tem- perature. ° F.	Pres- sure.			Si.	S.	P.	Mn.
1	453	2784	1500	50	50	2	48,000	1242	11	430	3.2	1.13	0.033	0.340	1.08
2	460	2772	1492	"	"	2	48,000	1217	10½	495	3.2	1.67	0.023	0.344	0.74
3	618	2256	1163	"	"	2	45,000	1237	13	490	3.5	1.38	0.027	0.336	0.75
4	676	1924	1010	"	"	4	45,000	1237	12½	490	3.8	1.71	0.036	0.354	0.73
5	597	2272	1208	"	"	4	45,000	1182	12	445	3.1	1.54	0.036	...	0.81
6	588	2226	1201	"	"	4	45,000	1197	12	445	4.5	1.34	0.035	0.354	1.10
7	594	2243	1216	"	"	4	40,000	1167	11½	515	5.7	1.33	0.038	0.352	1.14
8	501	2631	1481	"	"	4	42,000	1182	11½	490	4.9	1.55	0.039	0.340	1.49
9	426	2518	1444	"	"	4	45,000	1147	12½	435	3.9	1.32	0.042	0.324	1.27
10	551	2441	1406	"	"	4	42,000	1142	12½	290	4.6	1.07	0.049	0.356	1.10
11	514	2610	1440	"	"	4	42,000	1112	12	445	3.9	1.06	0.034	0.344	1.10
12	493	2716	1517	"	"	4	45,000	1062	12½	570	4.2	1.49	0.034	0.360	1.35
13	626	2185	1231	"	"	4	45,000	1087	13	495	4.0	1.30	0.040	0.324	1.29
14	629	2216	1224	"	"	4	40,000	1092	12½	440	3.4	1.13	0.039	0.330	1.21
15	541	2483	1378	"	"	4	40,000	1102	13	485	3.0	0.84	0.036	0.328	1.06
16	611	2085	1115	"	"	4	42,000	1097	13	485	3.1	1.13	0.038	...	0.93
17	514	2463	1345	"	"	2	45,000	1102	13	535	3.2	1.43	0.034	0.348	0.99
18	609	2111	1184	"	"	4	45,000	1087	14	505	3.3	1.49	0.033	0.340	1.19
19	582	2239	1294	"	"	4	45,000	1112	15½	520	2.3	1.33	0.036	0.340	1.15
20	531	2388	1347	"	"	4	45,000	1107	15	510	2.1	1.27	0.037	0.344	1.07
21	389	2903	1686	"	"	4	45,000	1102	15½	450	2.2	1.44	0.037	...	1.15
22	518	2891	1547	"	"	4	45,000	1072	15	430	2.4	1.24	0.048	0.324	1.08
23	598	2326	1443	"	"	4	45,000	1082	14	495	2.3	1.18	0.048	0.344	0.73
24	706	1835	1026	"	"	4	47,000	1037	15	515	2.4	1.33	0.045	0.340	0.62
25	605	2131	1193	"	"	4	45,000	1072	14½	520	3.0	1.28	0.038	0.328	0.62
26	585	2325	1268	"	"	4	45,000	952	14	515	2.5	1.15	0.041	0.336	0.77
27	688	1940	1104	"	"	4	45,000	1077	14½	485	3.0	1.17	0.040	0.300	0.77
28	539	2511	1394	"	"	4	42,000	1062	14½	485	2.8	1.23	0.033	0.296	1.35

Total, 15,742

Average Analysis of Materials.

	SiO ₂ .	Al ₂ O ₃ .	Fe.	Mn.	P.
Average iron ore analysis .	2.90	3.39	60.95	0.58	0.064

	Insoluble Residue.	Al ₂ O ₃ . Fe ₂ O ₃ .	CaO.	MgO.
Average dolomite analysis	3.26	1.35	29.51	20.70

	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.	S.
Average coke analysis .	6.27	21.82	1.52	69.89	0.50

Average blast temperature .	1123° F.
„ „ pressure .	13½ lbs.
„ top gas temperature .	478° F.

Materials Consumed per Ton per Month.

	Lbs.
Ore	3557
Dolomite	1296
Coke	2333

Total Materials Consumed during the Month.

	Tons.
Ore	24,998.3
Dolomite	9063.9
Coke	16,396.0
Scrap	289.1

Average Analysis of Products.

	Si.	S.	P.	Mn.
Average analysis of iron made	1.29	0.038	0.363	0.97

	SiO ₂ .	Al ₂ O ₃ .	CaO.	MgO.	FeO.	MnO.
Average slag analysis .	30.38	20.89	27.04	17.26	2.04	1.16

	CO ₂ .	CO.	H ₂ .	CH ₄ .	O ₂ .
Average gas analysis .	10.6	29.4	0.5	1.4	0.4

Average slag per ton iron . . 1469 lbs.

APPENDIX II.

Coke	15,000 lbs. at 75% C.	15,000 lbs. at 75% C.
Ore	19,000 „	23,000 „
Stone (dolomite)	9,300 „	9,300 „
1. Moisture in coke	5.5 per cent.	5.5 per cent.
2. Yield pig	63 „	63 „
3. Coke per ton pig	2,723 lbs.	2,250 lbs.
4. Ore „ „	3,556 „	3,556 „
5. Stone „ „	1,741 „	1,438 „
6. Slag „ „	1,814 „	1,498 „
7. Fe_2O_3 „ „	2,997 „	2,997 „
8. Stove heat	850° F.	1200° F.
9. Oxygen in ore	900 lbs.	900 lbs.
10. CO to reduce Fe_2O_3	1,575 „	1,575 „
11. CO_2 resulting	2,475 „	2,475 „
12. CO_2 in cubic feet	20,008	20,008
13. CO_2 from stone at 41 per cent.	713.81 lbs.	589.58 lbs.
14. CO_2 from stone (cubic feet)	5,770	4,766
15. Total CO_2 (cubic feet)	25,778	24,774
16. Carbon from coke	2042.25 lbs.	1687.5 lbs.
17. „ to pig	89.6 „	89.6 „
18. „ „ gases	1952.65 „	1597.9 „
19. Carbon in 1 cubic foot gas	0.0135 „	0.0135 „
20. Gas due to coke	144,640 cu. ft.	118,362 cu. ft.
21. „ „ stone	5,770 „	4,766 „
22. Total gas	150,410 „	123,128 „
23. CO_2 in gas	15,041 „	12,312 „
24. CO „ „	43,619 „	35,707 „
25. CO_2 produced (15)	25,778 „	24,774 „
26. CO_2 reduced to CO by reaction, $\text{CO}_2 + \text{C} = 2\text{CO}$, 10,737 cu. ft.		12,462 „
27. Excess reduction		1,725 „
28. Carbon required		58.2 lbs.
29. Coke equivalent		77.6 „
30. Pig per ore unit charged		6.47 tons
31. Extra coke dissolved in $\text{CO}_2 + \text{C} = 2\text{CO}$ reaction per charge		502 lbs.
32. Final gas, CO	29 per cent.	29 per cent.
„ CO_2	10 „	10 „

APPENDIX III.

THERMAL BALANCE SHEET ON "D" FURNACE.
CALCULATIONS BASED ON 1 TON OF PIG IRON PRODUCED.

BASED ON WORK OF "D" FURNACE FROM 2ND TO 8TH AUGUST 1924.
TATA IRON AND STEEL CO., LTD., JAMSHEDPUR, INDIA.

HEAT ABSORBED: THERMO-CHEMICAL CHANGES.

HEAT ABSORBED: THERMO-PHYSICAL CHANGES.

HEAT GENERATED: THERMO-CHEMICAL CHANGES.

Reduction of Ferric Oxide (Fe₂O₃).
Fe from Fe₂O₃ in ore = $3532 \times 58.4\% = 2063$ lbs.
Heat of formation of Fe₂O₃ per lb. of iron = 3143 B.Th.U.'s.
 \therefore Heat absorbed = $2063 \times 3143 = 6,482,000$ B.Th.U.'s.

Reduction of Silica (SiO₂).
Silicon in 1 ton of iron = $2240 \times 1.37\% = 30.68$ lbs.
Heat of formation of SiO₂ per lb. silicon = 12,600 B.Th.U.'s.
 \therefore Heat absorbed = $30.68 \times 12,600 = 386,700$ B.Th.U.'s.

Reduction of Manganese Oxide (MnO).
Mn in 1 ton of iron = $2240 \times 0.93\% = 20.83$ lbs.
Heat of formation of MnO per lb. Mn = 2976 B.Th.U.'s.
 \therefore Heat absorbed = $20.83 \times 2976 = 62,000$ B.Th.U.'s.

Reduction of Phosphorus Pentoxide (P₂O₅).
Phosphorus in 1 ton of pig iron = $2240 \times 0.349\% = 7.816$ lbs.
Heat of formation of P₂O₅ per lb. of phosphorus = 10,600 B.Th.U.'s.
 \therefore Heat absorbed = $7.816 \times 10,600 = 82,850$ B.Th.U.'s.

Decomposition of CaO.CO₂ in Dolomite.
Weight of CaO involved = $1367 \times 30\% = 410.10$ lbs.
Heat of formation of CaO.CO₂ per lb. CaO = 1451 B.Th.U.'s.
 \therefore Heat absorbed = $410.10 \times 1451 = 595,100$ B.Th.U.'s.

Decomposition of MgO.CO₂ in Dolomite.
Weight of MgO involved = $1367 \times 21.51\% = 294$ lbs.
Heat of formation of MgO.CO₂ per lb. MgO = 1319 B.Th.U.'s.
 \therefore Heat absorbed = $294 \times 1319 = 387,800$ B.Th.U.'s.

Decomposition of Moisture in Blast.
Weight of moisture involved = 87.17 lbs.
Heat of formation of H₂O per lb. H₂O = 5808 B.Th.U.'s.
 \therefore Heat absorbed = $87.17 \times 5808 = 506,200$ B.Th.U.'s.

Total Heat in Molten Pig Iron.
Weight of pig iron involved = 2240 lbs.
Heat required to bring iron to melting point (2100° F.) = 360 B.Th.U.'s.
Heat required for 2240 lbs. of iron = $2240 \times 360 = 806,400$ B.Th.U.'s.
Latent heat of fusion = 106 B.Th.U.'s.
 \therefore Heat absorbed = $2240 \times 106 = 237,440$ B.Th.U.'s.
Tapping temperature taken = 2600° F.
 \therefore Increase in heat after melting = $(2600^\circ - 2100^\circ) \times 0.2 \times 2240 = 224,000$ B.Th.U.'s.
Total heat carried in iron = 1,267,840 B.Th.U.'s.

Total Heat in Molten Slag.
Weight of slag involved 1624 lbs.
Specific heat from 85° F. 0.294
Melting point of slag 2230° F.
Heat required to bring slag to melting point = $(2230^\circ - 85^\circ) \times 0.294 \times 1624 = 1,024,000$ B.Th.U.'s.
Latent heat of fusion = 180 B.Th.U.'s. per lb.
 \therefore Heat absorbed = $180 \times 1624 = 292,320$ B.Th.U.'s.
Tapping temperature of slag = 2700° F.
 \therefore Increase in heat after melting = $(2700^\circ - 2230^\circ) \times 0.294 \times 1624 = 224,400$ B.Th.U.'s.
Total heat carried in slag = 1,540,720 B.Th.U.'s.

Sensible Heat of Exit Gases.

Analysis by Weight per Cent.	Weight of Gas.	Temperature.	Specific Heat.	B.Th.U.'s.
CO ₂ = 16.73	$\times 11,240$	$\times (292^\circ - 85^\circ)$	$\times 0.2169$	= 84,430
CO = 28.23	$\times 11,240$	$\times (292^\circ - 85^\circ)$	$\times 0.2426$	= 159,300
H ₂ = 0.10	$\times 11,240$	$\times (292^\circ - 85^\circ)$	$\times 3.409$	= 7,930
N ₂ = 53.13	$\times 11,240$	$\times (292^\circ - 85^\circ)$	$\times 0.2438$	= 301,400
Total .				553,060

Heat Carried in Water Vapour in Exit Gases.
Weight of water vapour involved 131.47 lbs.
Moisture from :
Ore $3532 \times 2\% = 70.64$ lbs.
Coke $2433 \times 2.5\% = 60.83$,,
Total . . . = 131.47 lbs.
Temperature on exit 292° F.
Sensible heat from 85° to 212° F. = $(212^\circ - 85^\circ) \times 131.47 = 16,700$ B.Th.U.'s.
Latent heat at 212° F. = $966 \times 131.47 = 27,100$ B.Th.U.'s.
Super heat up to 292° F. = $(292^\circ - 212^\circ) \times 0.48 \times 131.47 = 9049$ B.Th.U.'s.
Total heat carried away by moisture = 148,849 B.Th.U.'s.

Heat Carried with Cooling Water from Tuyeres, Bosh, and Hearth.
Weight of cooling water per ton of pig iron 111,600 lbs.
Original temperature of water 104° F.
Final temperature of water 112° F.
 \therefore Heat carried in water = $(112^\circ - 104^\circ) \times 111,600 = 892,800$ B.Th.U.'s.

Heat Generated in Combustion of Carbon.
Total weight of carbon 1872.10 lbs.
,, ,, exit gases 11.240 ,,

Analysis of Gases by Weight per Cent.		Weight of Carbon Contained in 11,240 lbs. of Gas
CO ₂	16.73	348.36 lbs. from coke
CO	28.23	1359 ,,
H ₂	0.10	
N ₂	53.13	

Heat generated by combustion of 348.36 lbs. of C into CO₂ = $348.36 \div 14,580 = 5,079,000$ B.Th.U.'s.
,, ,, ,, ,, 1359 ,, ,, CO = $1359 \div 4374 = 5,947,000$,,

Heat Generated in Formation of Silicates in Slag.
Weight of slag involved = 1624 lbs.
,, SiO₂ + Al₂O₃ = 839.20 lbs.
Heat generated on combination with lime = 270 B.Th.U.'s per lb. SiO₂ + Al₂O₃.
Total heat generated = $839.20 \times 270 = 226,700$ B.Th.U.'s.

Formation of Carbide of Iron.
Weight of carbon involved = 89.6 lbs.
Heat of formation = 1270 B.Th.U.'s per lb. of carbon.
 \therefore Heat generated = $89.6 \times 1270 = 113,800$ B.Th.U.'s.

Reduction of Sulphur.
FeS + CaO + C = Fe + CaS + CO (thermal effect of this allowed for elsewhere).
Weight of CaS involved = $1624 \times 2.01\% = 32.64$ lbs.
Heat of formation of CaS = 2358 B.Th.U.'s per lb. CaS.
 \therefore Heat generated = $2358 \times 32.64 = 76,960$ B.Th.U.'s.

HEAT GENERATED: THERMO-PHYSICAL CHANGES.

Heat Carried in by Blast.
Weight of blast = 7754 lbs.
Temperature (average) = 1179° F.
 \therefore Heat carried = $1179^\circ \times 0.237 \times 7754 = 2,166,000$ B.Th.U.'s.

Heat Carried in by Moisture in Blast.
Weight of moisture involved = 87.17 lbs.
Specific heat = 0.54 ,,
 \therefore Heat carried in by moisture = $87.17 \times 1179^\circ \times 0.54 = 55,490$ B.Th.U.'s.

THERMAL BALANCE SHEET.

Heat Absorbed.	B.Th.U.'s.	Per Cent.	Heat Generated.	B.Th.U.'s.	Per Cent.
1. Reduction of Fe ₂ O ₃ . . .	6,482,000	47.45	1. Combustion of C to CO . . .	5,947,000	43.54
2. " " silica . . .	386,700	2.83	2. " " C, CO ₂ . . .	5,079,000	37.18
3. " " MnO . . .	62,000	0.45	3. Heat generated in formation of carbide of iron . . .	113,800	0.83
4. " " P ₂ O ₅ . . .	82,850	0.61	4. Heat generated in formation of silicates in slag . . .	226,700	1.66
5. Decomp. of CaO.CO ₂ in dolomite .	595,100	4.36	5. Formation of CaS . . .	76,960	0.55
6. " " MgO.CO ₂ . . .	387,800	2.84	6. Heat carried in by blast . . .	2,166,000	15.83
7. " " moisture in blast . . .	506,200	3.71	7. Heat carried by moisture in blast .	55,490	0.41
8. Total heat in molten iron . . .	1,267,840	9.28			
9. " " " slag . . .	1,540,720	11.27			
10. Sensible heat of exit gases . . .	553,060	4.03			
11. Heat carried in water vapour in gases .	148,849	1.07			
12. Heat carried with cooling water . . .	892,800	6.54			
13. Balance-radiation loss, &c. . .	759,031	5.56			
Total . . .	13,664,950	100.0	Total . . .	13,664,950	100.0

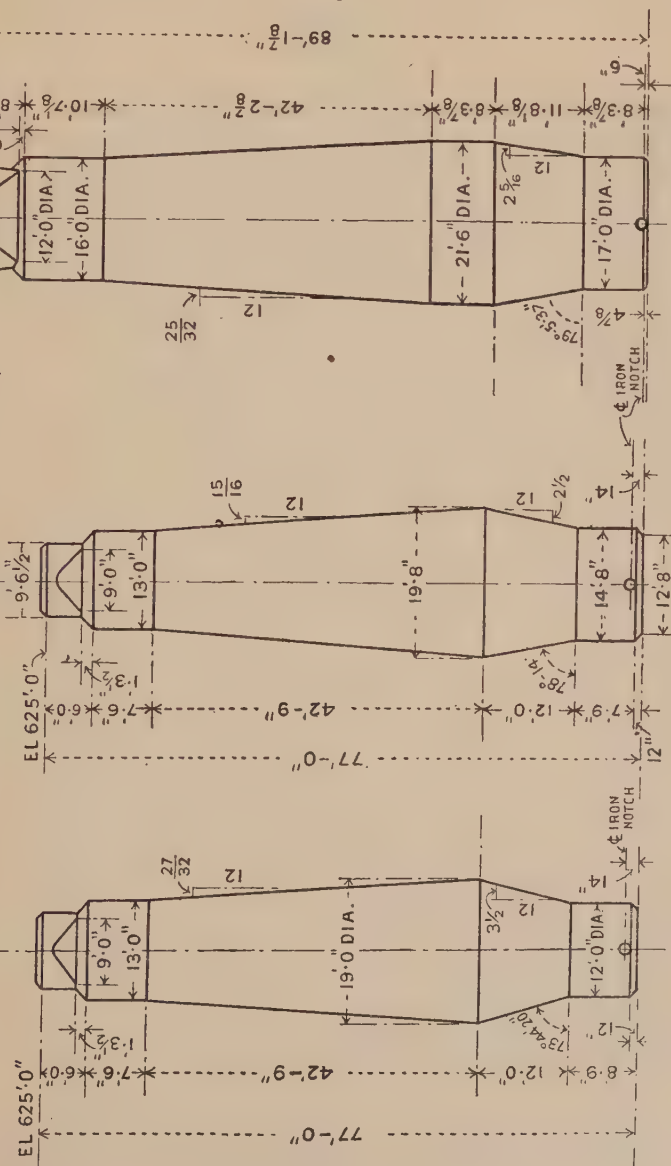


Fig. 1.

DISCUSSION.

MR. E. C. EVANS (London) pointed out that blast-furnace practice in India differed from that in Britain in the fact that they used an extremely pure ore and a very impure coke. One of the problems to be faced in India, which was getting more serious every year, was that of coke purity. The best coals in India used to contain ash to the extent of about 12 per cent., but that figure was considerably exceeded in the inferior coals that were now being worked. Indian coals consisted of bright and dull coals very intimately intermixed, and in order to separate them they had to be finely ground. By froth flotation it was possible to get about 50 to 60 per cent. of a comparatively pure coal with about 9 to 12 per cent. of ash, but the dull coal might run to 20 to 25 per cent. of ash. There were several points mentioned by the author on which he would be glad of further information. For example, it was stated that by increasing the stove heat and paying particular attention to the rotation of filling, the pressure on all the furnaces was reduced. Did he mean that the pressure was reduced primarily as a result of increase in stove heat, or was it a question of method of filling? Would he also give a closer definition of "rotation of filling"? He would like to ask one question relating to the furnace lines, namely, had the author found in Indian practice any difference between the life of the furnace linings on the old lines and the present lines? Could he give any idea of the output between successive relinings of the same furnace under the old and new conditions? When he (Mr. Evans) was at Jamshedpur he had paid very little attention to the blast-furnace side, but his impression of the coke there was that it was pushed rather sooner than was done in British practice, while the ovens at that time were worked at a slightly lower temperature than was the case in this country. Possibly that might not be the case now, since the new Wilputte plant had been put into operation. Speaking from memory, the coke although small seemed to be comparatively tough, indeed not less so than the coke produced in Derbyshire and other of our coalfields. He did not know whether Indian coke was more soluble than British coke, and he would like to have an opportunity of examining it in that respect, although the evidence given did not show that it was excessively soft. Apparently 4 per cent. of breeze was obtained at the coke bins. What size was that breeze? If it were less than $1\frac{1}{2}$ inch, 4 per cent. was certainly not more than was found in some English coalfields.

MR. JAMES HENDERSON (Member of Council) said there was no more important subject before the iron and steel trade at the present time than that of blast-furnace practice, particularly with regard to fuel

economy. There was undoubtedly very great room for improvement in many of the plants in this country, and the paper would give a useful lead to members of the various staffs in this country in directing them along the lines that ought to be followed.

Mr. A. HUTCHINSON (Member of Council) thought the paper was one of great interest. When Mr. Bury, the technical adviser to the Tata Company, returned to England during the past spring and gave some particulars of the remarkable results that had been obtained with soft coke in India, he naturally looked forward to the present paper with very great pleasure. The Tata Company, using very pure hæmatite ores, had succeeded in getting down their coke consumption to something like British practice, only in the latter case it had been done with good Durham coke and very inferior ore. He would like to ask the author how fine the materials, from which the coke was produced in India, were ground, and whether there was any possibility of improving the quality of the coke by grinding the coal still finer. He mentioned that point because in his own company very great benefit had been found to accrue from fine grinding. The question of the lining of the furnace was also a most important one. It rather looked from what was said in the paper as if very considerable economies had been effected in the furnace by altering the lining. He, like Mr. Evans, would be glad to know how the alteration of the lining affected the life of the furnace. Was the total output of iron for the life of the furnace likely to be increased by the alteration to the lining?

Mr. D. SILLARS (South Bank, Yorks.) said that the records contained in the author's paper were of the very greatest value to those engaged in industrial practice. There were one or two questions he wished to ask. First, what percentage of error did he consider his records contained? The author would not misunderstand him when he suggested that, for instance, his pig yield appeared to be very high. It was common with skip-charged furnaces to find that more ore was used per ton of iron than in the case of hand-charging. Secondly, he would like to know how the air was blown. Were turbo-blowers used, and how was the volume of air used per pound of coke determined? Was it merely calculated from the coke weight and gas analyses, or was it checked in any other way? Many errors arose in plant records in that connection. It was not suggested that the author's plant in particular was unlikely to give the performance that the record set out, but it was found that many errors up to 5 per cent. frequently arose in the determination of the volume of air blown. With regard to the theories put forward by the author, he thought there could be no question that the study of the lines of blast-furnaces had a very important bearing upon their economy in fuel. The unfortunate thing about a blast-furnace was that it was so seldom blown

out (particularly in this country) and re-lined, so that continuity in people's minds was not maintained. If a furnace were blown out ten or fifteen years after its erection, the ideas which were in the minds of people at the time of its erection had somewhat changed and continuity was frequently not preserved in the change made in the contour of the linings. A change of only a few inches could be made at one time with any certainty; radical changes, however reasonable they appeared to be, were unwise in the case of so long-lived a structure. He did not think the author would claim that the conception indicated in the paper was by any means a new one. The place where shrinkage of the burden occurred, due to incipient fusion, had been known for a long time to be the determining position at which the bosh should begin, and that again was a question of the temperature gradient of the furnace and the size of materials. With plant in which the materials were well sized the shrinkage was, of course, much more regular; where the sizing was not regular the shrinkage was usually less even. Sometimes a furnace ran well for some years, and then, owing to a change in the condition of the materials, it would work much less successfully. Furnace lines and furnace materials were interdependent; changes in one must be accompanied by appropriate changes in the other. The direction of the consequential change was usually clear, but the amount only a more or less informed guess. With regard to the change from the A and B furnace to the C and D furnace, he would like to ask if it would not also be necessary when the bosh was shortened to widen the hearth in order to preserve the same angle of bosh on the new furnace.

Mr. R. MATHER (London) remarked that there was one interesting point in blast-furnace practice in India not specifically mentioned by the author which, while it did not bear on the main purposes of the paper, was perhaps worth bringing to the notice of the members. In India they worked with a reasonably pure hæmatite ore low in phosphorus and yet produced a basic pig iron, the difficulty being that the coal contained so much phosphorus in the ash that it was practically impossible, using coke, to make an iron under about 0.35 per cent. of phosphorus. He thought one of the most notable features of the practice described was the regular grading in size of the solid materials going into the furnace, and that essential detail led to the good results now being obtained at Jamshedpur. He (Mr. Mather) found, on comparing the four sets of records in Appendix I. for the two newer furnaces for the two months of January and February 1925, that, after deducting the scrap charged, in the first two months of 1925 there were made in the two furnaces over 65,000 tons of pig iron containing over 1 per cent. silicon at the rate of nearly 560 tons per furnace per day, using 14 cwts. of fixed carbon in the coke per ton. That was with a burden which involved the production of 12 cwts. of slag per ton of pig. The figures should be com-

pared with those for British practice from the point of view of the amount of carbon in the coke, in order to discount properly the difference in ash content. He desired to emphasise the point that not only had the author obtained a fuel consumption better than was general, and certainly as good as the best in this country, but he had also obtained a very large output from each furnace unit. It had been urged that if blast-furnace men were to aim at very large outputs the quality of the iron might suffer. While he was Metallurgical Inspector to the Government of India he had occasion about two years ago to make a thoroughly independent test of the quality of Tata pig iron, and the remarks he was about to make applied also, he believed, to the Indian pig iron made by other firms there from very similar ore, very similar coke, and under similar conditions. He took several tons of pig iron, selected by himself from the stocks, to a totally independent foundry and had it melted under his own supervision. The results showed that a mixture of 80 per cent. of Tata No. 3 foundry iron with 20 per cent. of cast iron scrap which had originated from the same pig iron would give on a 2 in. \times 1 in. \times 3 ft. long transverse test-bar a breaking load of over 30 cwts. and a total deflection of nearly 0.5 in. If 20 per cent. of steel scrap were added he could obtain a breaking load of 40 cwts. with a deflection of over 0.6 inch, the tensile strength being over 15 tons per square inch. That, he thought, was useful testimony to the quality of the iron which was produced for ordinary foundry purposes, and it behoved blast-furnace men in this country, even though they were rightly very careful of their reputation for quality, to pay great attention to the very high outputs, combined with low fuel consumption, that were being obtained in India consistent with such good quality in the finished product. He noticed the author stated that he would have an opportunity in the near future of observing the effect on fuel economy resulting from shortening the boshes of the older furnaces. He hoped the author would favour the Institute again with the results of his observations when they became available.

Professor H. LOUIS (Vice-President) hoped that the author would complete the data he had given in the paper by stating the number and dimensions of the tuyeres and the height of the tuyere line, because those details were required to enable members to understand fully the furnace construction. Perhaps the author would also state whether there was any marked difference between the operation of the Indian furnace in the dry and wet seasons; he had often wondered what effect the wide variation of the humidity of the air would have on blast-furnace practice, and whether any useful lessons could be deduced from it. One or two questions had been asked about the quality of the coal in India. Some eighteen years ago he was sent out to India with the late Mr. E. P. Martin to investigate the question of iron-making in India. That was before the days of the Tata works,

when only the Bengal Company was working on coal-measure ores. The present huge hæmatite ore supplies were not then available, so that the practice was entirely different. He paid a great deal of attention to the coal and examined it in many ways, even by X-rays, perhaps one of the first applications of this agent to the examination of coal. He found that the ash was so very finely divided that he gave up all hopes of washing the coal on a large scale. He did not say it was impossible in the laboratory, but it appeared to be impracticable from a commercial point of view. He could therefore quite understand that serious difficulties on that account might be experienced in the future.

Mr. E. ADAMSON (Sheffield) said he desired to stress the point that Mr. Mather had raised in regard to the quality of the Indian pig iron. It had been his experience, from a foundry point of view, that if a blast-furnace were driven hard a product was obtained which did not give the same results in solidity and physical tests as that obtained from a furnace which was not hard driven. In these days of demands for efficiency in all departments of iron and steel works, it was satisfactory to know that instead of scrapping many of our blast-furnaces and rebuilding them on most modern lines, the output of the present furnaces could be increased by simply altering the lines of the furnaces and a few other details.

The Tata consumption of coke appeared to be very low, which was no doubt partially accounted for by the method adopted of charging only certain sizes of ore into the furnace. That would, of course, give freer gas circulation and so assist the rapid reduction of the ore.

Mr. E. E. WOOD (Wrexham) referred to the statement in the paper that the ash in the coke amounted to 21·4 per cent. He would be exceedingly indebted to the author if he would give the analysis of that ash, as it would form such a large proportion of the slag, in order that further comparisons might be made. He would also like to know if the author had found a very great difference in the dust losses in the blast-furnace under the varying conditions of the bosh.

On the conclusion of the discussion, the PRESIDENT proposed and the meeting carried by acclamation a hearty vote of thanks to the author for his interesting paper. Mr. Keenan had made the journey from America for the special purpose of presenting his paper in person, which friendly attention was most warmly appreciated by all those who had had the privilege of hearing him.

For correspondence and Mr. Keenan's reply to the discussion see p. 349.

Iron and Steel Institute.

A HIGH-FREQUENCY INDUCTION FURNACE.

By DONALD F. CAMPBELL (LONDON).

THE use of high-frequency currents for induction heating has added a new series of physical conditions to those under which metallurgical operations may be performed. Although still in its early stages of development, it provides an unrivalled means for rapid experimental and research work on alloy steels. It is being used for several metallurgical operations of the utmost importance, notably in the preparation of new special alloys having desirable electrical characteristics, which offer such opportunities for acceleration in submarine telegraphy that they will have a marked influence on inter-continental communications and commerce.

The early work in connection with high-frequency furnaces was carried out at Princeton University by Dr. Northrup, whose brilliant studies on the physical laws governing induction from high-frequency equipment led to the evolution of the first metal-melting furnaces.

Low-frequency induction furnaces have been known for forty years, and twenty years ago it seemed possible that they would to a large extent replace the crucible for high-grade steel-making. Further development was, however, prevented by the high capital expenditure necessary on electrical plant to obtain the very low frequencies required, the impossibility of making different alloys in succession, owing to the fact that part of the charge must be left in the furnace after each heat to start the next, and the advent of the arc furnace with its greater refining power. No low-frequency induction furnaces are now being used for steel-making in Great Britain, and comparatively few abroad.

Inductive heating has recently found wide application in the non-ferrous trade in furnaces having a vertical slot worked on normal commercial frequencies. But all these furnaces have the disadvantage of requiring an iron core, as the result of which the molten metal is contained in small channels surrounding the

iron core as well as in the main bath of the furnace. This entails wear and tear of the refractory material, and great length of furnace banks, as compared with the total weight of the metal contained in the furnace.

In the case of high-frequency heating, the ideal form of container is available, a cylindrical vessel holding a maximum weight of metal with a minimum of radiating surface and refractory material exposed to corrosive action.

Obviously, inductive heating is superior in thermal efficiency to any arc furnace or fuel-fired equipment, owing to the fact that the heat is actually generated in the charge to be melted, and consequently there is no loss of heat in the passage through refractory containers as in crucible furnaces, or in flue gases as in the case of open-hearth or reverberatory furnaces.

The high-frequency furnace has an immensely steep heat gradient between the molten metal and the outside of the furnace, the distance between molten platinum at, say, 1900° C., and a water-cooled copper coil, being only $\frac{3}{4}$ inch in platinum melting furnaces. This somewhat extraordinary fact does not produce excessive heat losses owing to the rate of input of calories into the charge, and the loss, being a function of time, is only considerable during the last few minutes of the melting operation, when the temperature of the metal is high.

The great disadvantage of high-frequency melting lies in the difficulty and expense of obtaining the necessary equipment to produce high-frequency currents, this problem being still in its early state of development, but its solution is advancing along several different lines with great rapidity.

A furnace installation consists of a source of high-frequency current, with suitable power factor correction, and a furnace of extremely simple design.

High-frequency currents may be obtained by means of rotary generators, valves, or a combination of spark gaps and condensers. The latter equipment was that first used by Dr. Northrup, and it has been applied in the case of the many small furnaces used for the melting of platinum and for general research work. Spark gaps and valves are at present available for small units only, and are not the robust type of machinery desirable for metallurgical works, but they will be gradually replaced or supplemented

by ordinary rotating high-frequency generators, as the demand for larger melting units increases. Such machines can now be obtained of simple and substantial construction up to 500 kilowatts capacity, though great accuracy and good workmanship are required in their manufacture.

The frequency required varies according to the size of furnace and quality of metal to be melted. The design of furnaces and high-frequency equipment involves a high degree of electrical and metallurgical experience, for the factors involved are not all well understood, and figures obtained from involved mathematical calculations must be interpreted with liberal additions from empirical results.

Unfortunately, all high-frequency electrical generators are expensive at the present time, but it is probable that the cost will be reduced.

The high-frequency furnace (see Fig. 1) consists merely of a container or crucible (C) placed inside a flat cylindrical coil (A). The intermediate space between coil and crucible, which generally does not exceed 1 inch, is filled with zircon or other insulating material contained in a silica or mica sleeve. The crucible or container may be of very thin construction, as it fulfils a different function from an ordinary crucible. If it be $\frac{1}{2}$ inch thick, there is a distance of only $1\frac{1}{4}$ inch between the coil, which is generally water-cooled, and the molten metal, which may be heated to over 2000° C. Thus a greater temperature gradient is obtained than in any other process of melting metals in bulk.

As the heat is generated within the metal itself, the temperature of the crucible is very much lower than that of the metal and the heat passes from the metal to the crucible, and is not conducted through the crucible walls, as in other processes. Consequently reactions between the metal and the crucible walls are reduced to a minimum, and crucibles of material quite inadmissible for melting certain metals by ordinary methods stand well in the furnace.

Also the crucible is supported outside by well-packed ground zircon, and even if a crack occurs there is seldom loss of metal, or any tendency for the crucible to break in pieces. Thus, an ordinary clay crucible, such as is used for gold assays, will make from ten to thirty heats of nickel-iron alloys containing less than 0.02 per cent. of carbon. This proves that the conditions under

which the crucible works are fundamentally different from other processes.

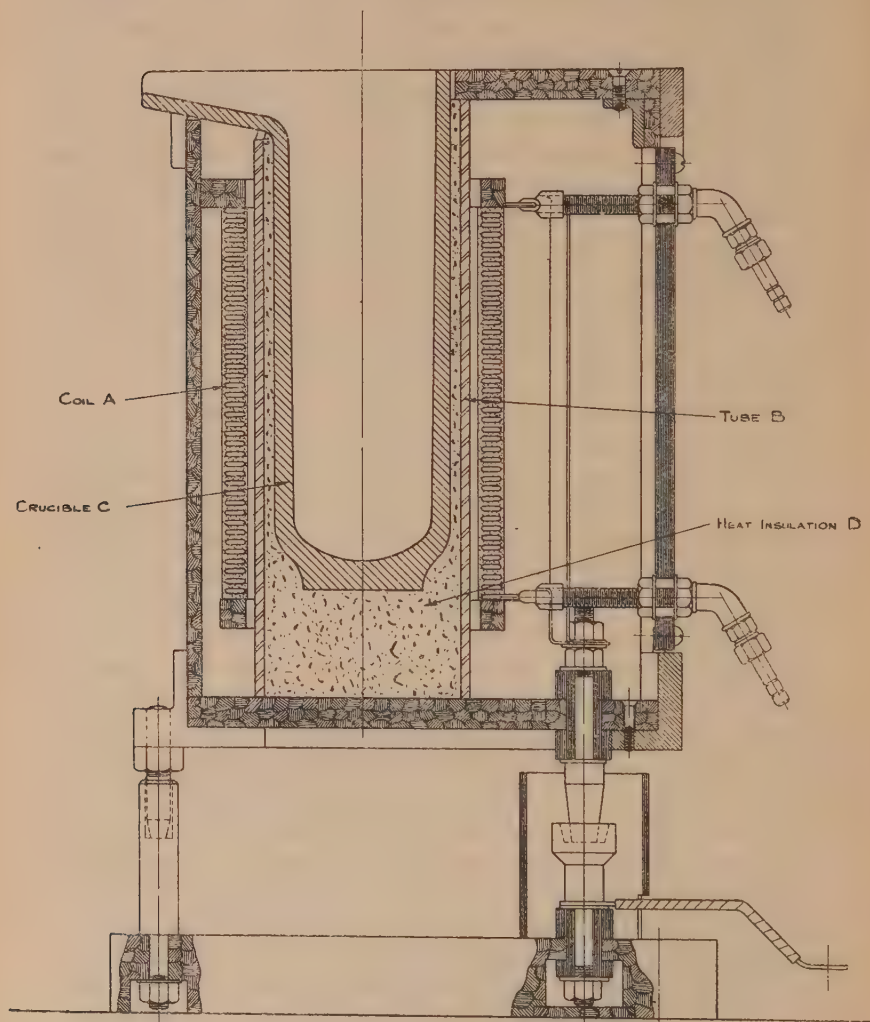


FIG. 1.—High-Frequency Crucible Furnace.

As the container is an ordinary crucible of cylindrical form, there is no necessity to leave metal in the furnace, or to have

narrow channels or any of the other features which have rendered the old type of induction furnace uneconomical and obsolescent for the steel trade.

High-frequency furnaces mix the charge intensely, the surface of the molten metal being pronouncedly convex, owing to the violent upward current at the centre of the liquid mass. This is a great advantage for the manufacture of alloys containing metals which do not readily mix, and difficult alloys can be melted with exceptional uniformity.

The frequencies used may be termed high or medium, and have varied from 20,000 to 400 periods per second, the lower figures being applicable to the larger furnaces for melting nickel-silver and similar alloys. Furnaces of a capacity of 600 lbs. are now working on certain nickel alloys, and this method of melting is worth consideration by makers of tungsten and cobalt crucible steel and anyone engaged in the manufacture of alloys of the highest quality for electrical work where freedom from carbon is of the utmost importance.

Capital cost of equipment is high, but this may be reduced in the future. The rate of melting is rapid, and the conditions of working exceptionally clean, accurate, and comfortable for the workmen.

Thermal efficiency is high, but the total consumption of kilowatt-hours per ton melted is in excess of good arc furnaces. This may be improved in the future, as the excessive losses occur in the comparatively undeveloped equipment now used for producing high-frequency current and are not inherent to the furnace system. The power factor of the furnace is low, but this can be counteracted to any desired degree by the use of one of the various devices well known to electrical engineers, such as condensers or synchronous motors, which involve some capital expenditure, but do not add appreciably to the working cost.

High-frequency heating may be found useful in the forging and heat treatment of steel, especially in the case of small objects of irregular shape, as the heating effect is to a great extent independent of the shape of the object submitted to the field. At present the principal application of this method of heating is in the preparation of alloys of nickel and iron with small percentages of other metals, and the lowest possible amount of carbon, which

are used for the manufacture of continuously loaded cables. By the use of this metal the speed of signalling on long-distance submarine cables has been raised from a maximum of 300 letters per minute for the old type cable to 1800 with the continuously loaded cable. This performance was obtained on a cable from the Azores to the United States and has given an entirely new aspect to the economics of submarine cabling, which, coupled with the secrecy and reliability of this form of transmission, ensures extensive demands for a larger production of this remarkable series of alloys.

The first commercial application of high-frequency melting in Europe was made by a British firm for the preparation of nickel-iron alloys for submarine cables. The research work pursued in order to find a suitable alloy was thereby much facilitated, and quickly resulted in the perfection of the series of alloys known under the name of "Mumetal" (so called because the Greek letter μ is the symbol for permeability). These alloys have highly desirable characteristics, and by their use the speed of cabling can be increased seven to eightfold.

A typical mumetal alloy has the following composition :

	Per Cent.
Nickel	74.0
Iron.	20.0
Copper	5.3
Manganese	0.7

An alloy of this composition has a magnetic permeability of 7000. Low hysteresis loss with a very high permeability at low magnetising forces are the characteristics chiefly required in these metals.

The composition of the mumetal may be varied according to the type of cable which it is proposed to use, and the annealing may be adjusted to give either (a) maximum neutral permeability, (b) maximum permeability at magnetic saturation, or (c) high or low fields for magnetic saturation.

The range of alloys developed for this class of work contain from 74 per cent. to about 50 per cent. of nickel, with percentages of iron varying from 20 to 25, and certain quantities of copper and manganese, but in every case freedom from carbon is one of the primary essentials, and for this reason the high-frequency furnace has proved the only suitable melting equipment.

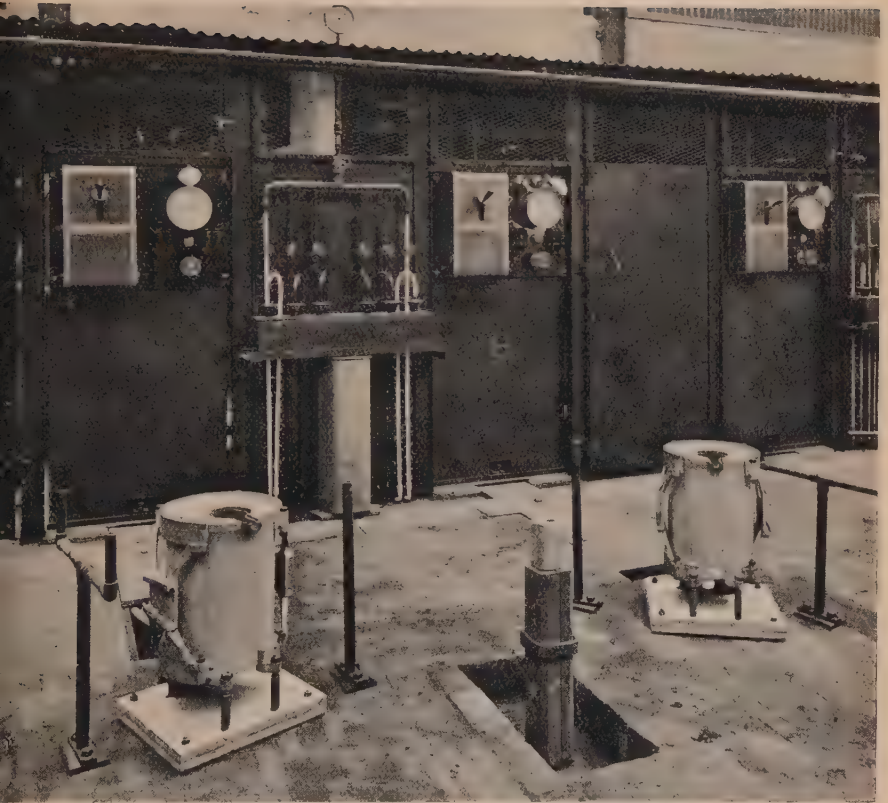


FIG. 2.—Installation of High-Frequency Crucible Furnaces.

In certain types of cable an increase in electrical resistance of the alloys is desirable, and in this case an extra element, which may be tungsten, chromium, silicon, vanadium, titanium, molybdenum, or aluminium, may be added in small quantities.

The furnace will also find use in the preparation of other alloys for telephonic apparatus, transformers, and in the development of the electrical alloys, which have not received the attention they deserve either from metallurgical or electrical engineers, although they offer a field of research which will certainly yield good results. Among these may be mentioned magnet steel containing a high percentage of cobalt.

The equipment referred to at present consists of forty-two small converter units, each of 35 to 40 kilovolt-ampere capacity, fitted with furnaces capable of melting 20 lbs. of nickel-iron alloys of exceptional purity in forty to forty-five minutes. Two or more converter units may be used on single furnaces of double or treble this capacity. The melting capacity is several tons per day, and a steady and continuous output is being maintained under strictly commercial conditions.

As a crucible furnace the equipment illustrated (Fig. 2, Plate VI.) has many attractive features, and is worth the attention of manufacturers who are interested in the improvement of alloy steels and other metals, especially those which may find wide application in the growing demand for improved alloys in the electrical industry.

The advantages of high-frequency furnaces for research work are very great, owing to the speed with which small heats can be made, either *in vacuo* or in air. In one instance, where an investigation was being made into the properties of a series of alloys with a relatively high melting point, twenty 2-lb. heats were made in eight hours. The consequent saving of the investigator's time and the increase in the amount of work he was able to perform are obvious.

In conclusion, the discovery of the two principal alloys used for cable loading, permalloy and mumetal, was made possible by the use of a high-frequency furnace, and further investigations are now being made in several different countries which may result in the discovery of new alloys with properties previously unknown.

CORRESPONDENCE.

Mr. F. W. HARBORD (Vice-President) wrote that the high-frequency induction furnace described by the author was of the greatest interest to all those engaged in metallurgical work, as it enabled alloys to be produced in a neutral or reducing atmosphere as might be desired. It was of special interest in view of the possibilities it opened up for the preparation of carbon-free iron alloys on an industrial scale, provided electrical engineers could reduce the cost of the high-frequency electric generators. He would like to ask the author if he could give some further information as to the industrial applications of that furnace, and if in his opinion there were any reasonable probability that in the near future the cost of the generators would be appreciably reduced. There was no doubt there were many industrial purposes for which the furnace could be used, provided the capital cost could be considerably reduced, and one of the advantages of a paper of that kind was that it brought before the electrical engineers the necessity for a furnace of that type, and might stimulate them to give special attention to improving and reducing the cost of the higher frequency generators, so that the furnace might be used industrially for the production of the less expensive alloys, such as some of the alloy steels.

Mr. J. FERDINAND KAYSER (Sheffield) wrote that throughout the paper no effort had been made to substantiate, in any way, the claims made for the high-frequency induction furnace. Having been associated with the development of cobalt magnet steels from the very beginning, he (Mr. Kayser) was particularly interested in the statement that the use of a high-frequency induction furnace would certainly yield good results when used for the production of such steels.

Assuming that a 36 per cent. cobalt magnet steel could be produced in the crucible furnace at a cost of, say, 5s. per lb. and give a BH_{\max} value of 1,000,000 C.G.S. units, he (Mr. Kayser) would like to hear what increased efficiency might be expected from a similar product melted in a high-frequency induction furnace.

The claim that such a furnace would have very great advantages for research work was not substantiated by the instance quoted. In the early part of the war, when on the research staff of the Spartan Steel Company, he (Mr. Kayser) constructed a small gas and air furnace, which would easily melt twenty 2-lb. heats of high-speed steel in eight hours, using town gas and air from high-pressure air mains, with which most steelworks were equipped. The furnace and burners cost not more than £3, and the gas consumption was approximately 1000 cubic feet per hour.

The statement that the discovery of Permalloy was made possible by the use of a high-frequency induction furnace could not be correct in view of the fact that, according to all reports received in this country, the properties characteristic of Permalloy were discovered during a general investigation of Ni-Cr-Fe alloys melted in an ordinary furnace. While such a very high price was being obtained for such alloys, the high-frequency induction furnace would probably be used to some extent for their production but, unless the cost of the initial installation was brought down to a fraction of its present price, it would not be long before the same alloys were made in ordinary gas- or coke-fired furnaces.

Mr. CAMPBELL, in reply to Mr. Harbord's question as to whether there was any reasonable probability that the cost of high-frequency generators would be appreciably reduced, wrote that the cost of high-frequency generators had been greatly reduced owing to manufacturers realising that the market for that type of equipment was likely to expand. Since the paper was written contracts had been let to leading manufacturers for generators of 100 kilovolt-ampère capacity at the moderate price of £3 to £4 per kilovolt-ampère, at which price robust machines of normal design could now be obtained. The earlier difficulties in that connection had been largely overcome, as lower frequencies than those required for small experimental furnaces could be used in the case of the 600-lb. melting units in use to-day for the melting of alloys.

In reply to Mr. Kayser's criticism of the paper, he thought there were no claims made for the furnace beyond a statement of what had already been done, and a few suggestions of possible future applications which might be worth the consideration of steel-makers.

The author could at present give no comparative tests of the relative electrical properties of cobalt magnet steels made in the high-frequency and other melting furnaces. The manufacture of metals of the permalloy type was found to be most conveniently accomplished in high-frequency furnaces owing to the necessity for absolute purity and extremely low carbon content of the alloys to give the best electrical characteristics, which properties were attainable by that method of heating.

Iron and Steel Institute.

THE TENSILE PROPERTIES OF SINGLE IRON CRYSTALS AND THE INFLUENCE OF CRYSTAL SIZE UPON THE TENSILE PROPERTIES OF IRON.

BY PROFESSOR C. A. EDWARDS, D.Sc., AND L. B. PFEIL, M.Sc., A.R.S.M.
(BOTH OF UNIVERSITY COLLEGE, SWANSEA).

PART I.

THE TENSILE PROPERTIES OF SINGLE IRON CRYSTALS.

At the May meeting, 1924, of this Institute, the authors presented a paper on "The Production of Large Crystals by Annealing Strained Iron."⁽¹⁾ Towards the end of that paper an account was given of a few tests which had been made on single iron crystals. The work has now been extended, and in the present paper the authors give an account of the experiments they have made during the past year.

Preparation of the Iron Crystals.

The material was of the same analysis as that employed previously, *i.e.* C 0.13, Si 0.023, Mn 0.44, S 0.028, P 0.020 per cent. The crystals tested were prepared in much the same way as was described in the earlier paper, some small modifications having been introduced, however, which allowed very large crystals to be made with greater certainty. The chief modification was in the method of producing the correct initial grain-size. In the previous paper, the best grain-size was stated to be 120 grains per square millimetre, and was obtained by decarburising for forty-eight hours at 950° C. For these further tests the same grain-size was obtained by decarburising at 875° C. for forty-eight hours, followed by heating to 1000° C. for twelve hours and then slow cooling.

A large number of strips 8 in. \times 1½ in. \times ⅛ in. was obtained, each strip consisting of one large crystal in the central part. In every case, it was necessary to remove the surface film of fine

crystals by careful filing before the existence of the large crystals could be detected by light etching. The filing was so conducted that, at the end of the operation, all the crystals had the same uniform thickness.

The test-pieces were cut from the crystals with the aid of a manganese steel templet, this ensuring that all the test-pieces were of exactly the same size, and further that the bending of the exceedingly soft metal would be impossible.

The important dimensions of the single crystal test-pieces were: parallel portion, length, 2.5 inches; width, 0.75 inch; thickness, 0.110 inch; giving a cross-section of 0.0825 square inch.

Method of Testing.

The tensile testing machine employed was a 10-ton Buckton. The load was increased by 0.01 ton every minute, equivalent to a rate of loading of 1 ton per one hundred minutes. In the early part of each test elongations were measured by means of a Cambridge Scientific Instrument Company's extensometer, using a 2-inch gauge length. Readings were accurate to one ten thousandth of an inch; readings between divisions being judged by eye to about one hundred thousandth of an inch.

After the removal of the extensometer, elongations were measured by means of dividers and a steel rule, to an accuracy one two hundredth of an inch.

Stress Elongation Curves.

In Fig. 1 are shown curves obtained by plotting stress against elongation for some of these tests. Fig. 2 shows the first portions of the curves on a much larger elongation scale. It is at once apparent that these curves are more like those which are usually obtained with non-ferrous metals, such as copper, than those usually obtained from finely crystalline iron or steel.

The curves show that up to a stress of about 2 tons per square inch the strain was proportional to the stress, and that there was no well-defined "yield point." The "limit of proportionality" and the "elastic limit" coincided, or were so near together as to make it impossible to distinguish one from the other. Some permanent set occurred before the "limit of proportionality" was reached, but it was so minute in amount as scarcely to exceed the

experimental error (one hundred thousandth of an inch), and it has therefore been neglected.

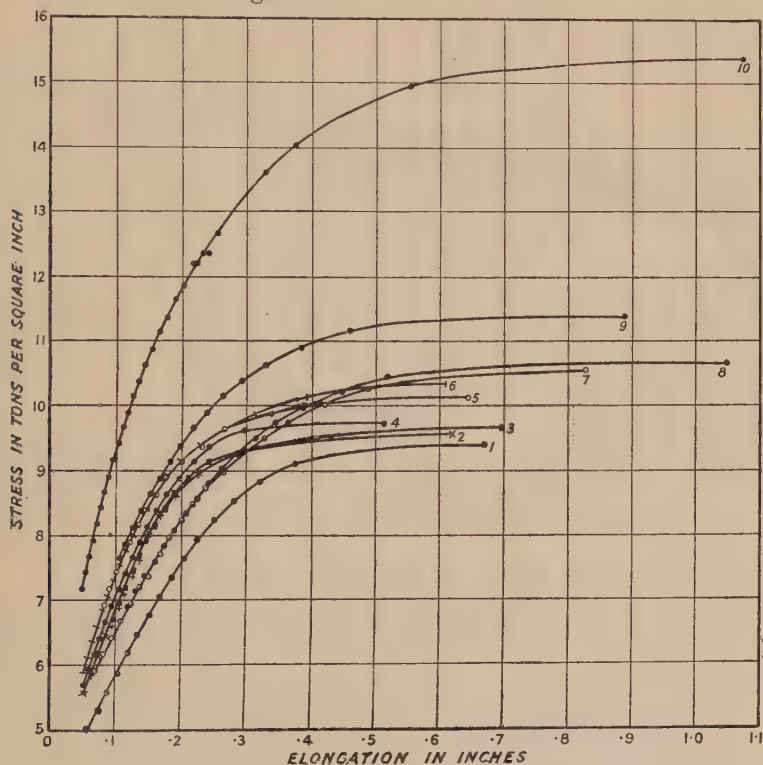


FIG. 1.—Single Crystals. Stress Elongation Curves.

TABLE I.

No. of Test.	Limit of Proportionality. Tons per Sq. In.	Tensile Strength. Tons per Sq. In.	Elongation. Percentage.	Modulus of Elasticity. Tons per Sq. In.
1	1.90	9.38	33.5	13,320
2	2.46	9.54	31.0	12,250
3	2.52	9.57	35.0	12,040
4	2.28	9.70	35.75	11,200
5	1.725	10.11	32.3	12,140
6	2.00	10.33	30.5	12,540
7	2.15	10.52	41.5	12,850
8	2.26	10.65	52.5	11,880
9	2.08	11.38	44.5	10,000
10	1.975	15.38	53.65	11,940

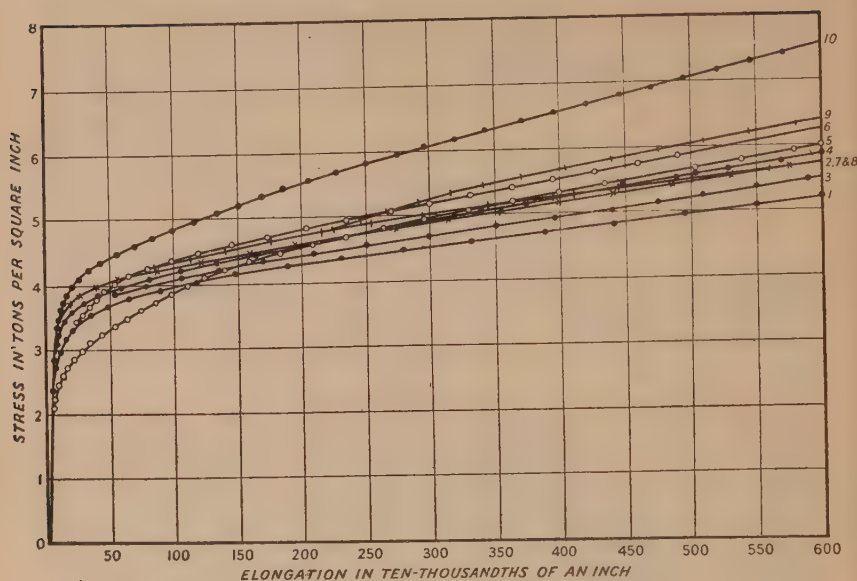


FIG. 2.—Single Crystals. Stress Elongation Curves.

Table of Tests on Large Single Crystals.

In Table I. will be found the values obtained in these tests for :

- (a) The limit of proportionality (tons per square inch).
- (b) The tensile strength (calculated on the original area).
- (c) The elongation (percentage on 2 inches).
- (d) The modulus of elasticity (tons per square inch).

The most striking feature of the figures in this table is the remarkable constancy of the values for tensile strength. With two exceptions, the figures for tensile strength fall within a range of 1.27 tons per square inch, the average value of eight tests being 9.98 tons per square inch, the maximum value 10.65 and the minimum 9.38 tons per square inch. One of the exceptions is only 1.4 tons above the average, but the other is 5.4 above, or over half as much again.

Tensile strength figures for four tests on single iron crystals have already been published by the authors in their reply to the discussion by Professor Carpenter on their previous work.⁽²⁾

These are as follows :

No. of Test.	Tensile Strength
A	9.72
B	9.72
C	9.94
D	9.61

In view of these earlier tests, the authors were not surprised to find again this constancy of tensile strength in single crystals—indeed they were rather surprised to find any one crystal with a strength 50 per cent. greater than the average.

In the tests on single aluminium crystals carried out by Carpenter and Elam,⁽³⁾ the values given for tensile strength were from 60 per cent. to 90 per cent. of that of the finely crystalline aluminium. Finely crystalline iron has a tensile strength of about 20 tons per square inch. The single iron crystals gave values, therefore, between 47 per cent. and 53 per cent. of that of the finely crystalline aggregate, making an exception when the figure amounted to 77 per cent. Professor Carpenter has already commented upon this difference in the behaviour of aluminium and iron crystals.⁽⁴⁾

The values found for the limit of proportionality were all very low compared with that of finely crystalline iron, in which the limit of proportionality is about 8 tons per square inch. The average value for the single crystals is 2.19 tons per square inch, which is little more than one-fourth of that of finely crystalline iron. The maximum value for a crystal was 2.69 tons, or 0.5 ton above the average; the minimum value 1.725 tons, or 0.465 ton below the average.

There appears to be no relation between the values for tensile strength and for the limit of proportionality. For example, the four crystals giving the lowest tensile strength values include three high values and one low value for the limit of proportionality; the four crystals with the highest tensile strength include two high limits of proportionality, one low, and one average value.

It should be especially noted that the crystal which gave a tensile strength of 15.38 tons per square inch had a low limit of proportionality amounting to only 1.975 tons per square inch.

Elongation.

In the case of the elongation figures, there appears to be some tendency to a variation in accordance with the tensile strength figures. The greatest elongation (53.65 per cent.) was obtained in the case of the strongest specimen (15.38 tons per square inch), the least elongation (31.0 per cent.) in the case of a crystal breaking at 9.54 tons per square inch. The figures for elongation are remarkably variable considering the constancy of the tensile strength values.

Modulus of Elasticity.

The modulus of elasticity varied from 10,000 tons to 13,320 tons, the average being 12,016 tons. In Fig. 3 are plotted the points obtained for the crystals up to the elastic limit. It will be noticed that the slope of these curves does not vary very greatly—this, of course, indicating that no wide variations in the modulus of elasticity existed. This is perhaps not surprising when it is remembered that the condition of a metal (cold-worked, annealed, &c.) has a very small effect upon this property.

Types of Fracture.

In Plate VII. are shown photographs of broken single crystal test-pieces which illustrate the types of fracture obtained up to this stage of the investigation.

The first four test-pieces (A, B, C, and D) show fractures which are very similar. A, B, and C are single crystal pieces, while D shows a piece composed of two crystals in the parallel part. This type of fracture was very similar to Carpenter and Elam's Type II. in aluminium crystals.⁽⁵⁾ This type of fracture is typical of those crystals which broke at a stress of about 10 tons per square inch. Most of the crystals broken, therefore, gave fractures of this kind.

During the test very little alteration took place in the breadth of the specimens, the usual change being from 0.75 inch wide at the commencement of the test to about 0.725 inch wide after fracture. A very considerable change, however, took place in the thickness of these crystals. Before the appearance of any sign of

fracture, the thickness was reduced by 25 to 50 per cent. At the fracture the crystals drew down to a knife-edge and parted in a

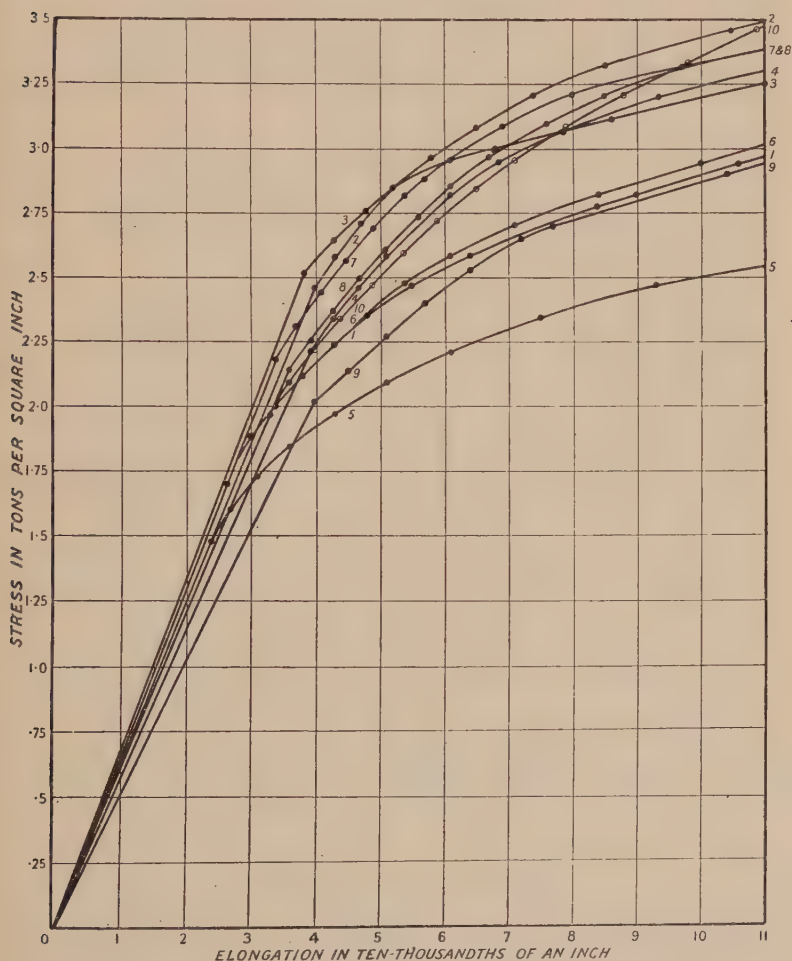


FIG. 3.—Single Crystals. Stress Elongation Curves.

straight line nearly at right angles to the axis of the test-piece. In many of these cases the cross-section changed from a rectangle to a parallelogram; the change was not very marked, and cannot be distinguished in the illustrations.

Test-pieces E and F (Plate VII.) show a very different type of fracture, rather like that of Carpenter and Elam's Type IV.⁽⁶⁾ During the test the crystal both narrowed and thinned, and showed a marked tendency for the cross-section to change from a rectangle to a parallelogram. In the case of piece F this is clearly seen in Plate VIII., where the fracture is illustrated at a magnification of 2 diameters (slightly reduced).

At the point of fracture the crystals necked and broke without drawing to a knife-edge. Just before parting, a large slip occurred on a plane making an angle of 45° with the length of the strip and with a "dip" of 45° .

The tensile strength figures were 10.65 tons for F and 11.38 tons for E, these being rather higher than those obtained with the first type of fracture. The elongation figures were, for F, 52.5 per cent., and for E, 44.5 per cent., these being also higher than for the first type of fracture. The limit of proportionality figures were little different from those of the first type.

The one crystal which broke at 15.38 tons per square inch gave a fracture different from the two types so far mentioned. The crystal narrowed and thinned, and also necked at the fracture. The elongation (53.65 per cent.) was the highest recorded. No illustration has been given, as the general appearance of the fracture was very like that obtained from finely crystalline iron or steel. In the first ten tests which the authors carried out on single crystal test-pieces, these three were the only types of fracture obtained. Seven fractures belonged to the first type (A, B, C, Plate VII.), two belonged to the second type (E and F, Plate VII.), and one to the third type (not illustrated).

The Consideration of Results.

The remarkable proportion of the tests which have given the same low figure for tensile strength seems to call for some explanation. Eight tests out of ten gave 10 tons per square inch tensile strength. To these eight should be added the four tests previously published, making in all twelve tests giving 10 tons out of a total of fourteen.

The orientations of the twelve crystals were not identical. This is clearly shown by an examination under oblique illumina-

tion. Further, identical orientations would almost certainly mean identical elongations under tensile pull, and the elongations given by the twelve crystals were far from similar.

A satisfactory explanation must therefore account for both a similarity of orientation to give equal tensile strength values and for a variation in orientation to account for the varied appearance of the etched crystals. The authors consider that the lowest value for tensile strength in an iron crystal will be obtained when two slip planes of the crystal make angles of 45° to the axis of stress—that is, when two planes coincide with planes of maximum shear—and that higher values for tensile strength will be obtained when no planes make this angle. The authors would like to emphasise that, in their opinion, the really important factor is the angle between the planes and the axis of stress, and not the relation between the position of the planes and the surface of the specimen.

There is still some doubt as to whether an iron crystal during tensile pull slips upon dodecahedral planes or upon cube planes. Slip in a crystal usually occurs most easily on the planes containing the greatest number of atoms per unit area. In the case of alpha-iron, these are the rhomb-dodecahedral planes (110). Evidence, however, has been brought forward from time to time which favours the supposition that slip in alpha-iron takes place on the cube planes (100). Later in this paper a description is given of fractures in a crystal which is of interest in this connection.

Both in the cube and in the rhomb-dodecahedron there are planes at right angles, hence making it possible to have two planes at 45° to the axis of stress. Fig. 4 is drawn to illustrate how an indefinite number of orientations are possible always fulfilling the requirements of two planes at 45° to the direction of stress. The axis of stress is vertical, and the cube so placed that the axis cuts the middle points of two opposite sides. By swinging the cube about the axis, an indefinite number of orientations may be obtained always preserving two planes at 45° to the axis of stress.

Fig. 5 illustrates the same thing, assuming that it is the planes of the rhomb-dodecahedron that are of the greatest importance. In this case there would always be four planes making angles of 45° to the axis of stress.

Evidence has already been published upon which the authors

based their opinion that, in the majority of the large crystals they had grown, the orientation was such as to provide two slip planes at nearly 45° to the angle of stress. Crystals with a different orientation may have been produced by some accident, such as non-axial straining, or some accidental local deformation initiating growth of a crystal of unusual orientation. Up to the present

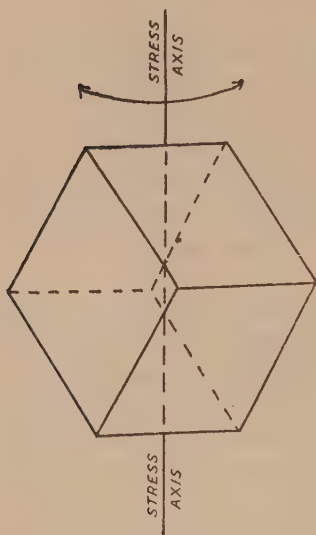


FIG. 4.

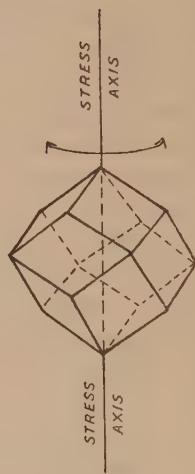


FIG. 5.

The plane of the paper represents the surface of the flat test-piece. The axis of stress is vertical. The position of the cube represents the orientation of the crystal.

they have been unable to determine the exact orientations of the crystals they have tested, but in many cases have kept aside small portions of the crystals (strips about 1 in. \times $\frac{1}{8}$ in. \times $\frac{1}{4}$ in. removed undamaged during the machining of the test-pieces), from which they hope to obtain the actual orientations of the crystals they have tested.

It will be very interesting to find whether there is a greater tendency in the case of iron than aluminium for large crystals grown from strained material to have a uniform orientation. Professor Carpenter and Miss Elam⁽³⁾ found that in the case of

aluminium crystals the orientation varied to a great extent. Professor Carpenter⁽⁷⁾ stated that "The different types of extension and fracture shown in their test-pieces were very clear evidence on that point, and had been confirmed by the X-ray investigation of the positions of the crystal axes."

Tests on Smaller Iron Crystals.

In a private communication to the authors, Miss Elam stated that she had determined the orientations of a number of crystals in an iron strip and had found no similarity. These crystals, the authors believe, were each about $\frac{1}{2}$ inch in diameter.

It occurred to the authors that if they carried out some tensile tests on crystals smaller than those of the first series they might obtain tensile strength values showing a much greater variation.

Crystals were selected, each of which would permit a $1\frac{1}{2}$ inch parallel portion and a 1 inch gauge length. Such test-pieces were broken in the tensile machine, obtaining values for tensile strength and for percentage elongation on 1 inch. In Table II. are shown

TABLE II.

No. of Test-Piece.	Tensile Strength. Tons per Sq. In.	Elongation. Percentage.
30	9.67	55.5
31	9.725	66.0
32	9.92	60.0
33	9.94	33.5
34	9.96	50.0
35	9.97	53.0
36	10.02	52.5
37	12.30	72.0
38	13.69	66.0
39	14.00	84.5
40	14.83	58.0

the figures obtained. Of the eleven tests, seven gave results closely approaching 10 tons per square inch for tensile strength, and breaking with a straight line knife-edge fracture. The remaining four tests gave results varying from 12 to 15 tons per

square inch, with various types of fracture, these crystals being therefore of very different orientations from the other seven.

The authors admit that fourteen and eleven tests respectively are not very satisfactory for determining averages, but there can be no doubt that the second set of tests on the smaller crystals indicates a greater variation of orientation than was shown by the first series on the largest crystals. It will be noticed that the elongations given in Table II. are, on the average, greater than those in Table I., this being due, no doubt, to the elongations having been measured on a 1 inch gauge length instead of on a 2 inch gauge length. A general tendency may also be noticed for the stronger crystals to break with a greater elongation than the weaker ones.

Test-piece G in Plate VII. shows a very peculiar type of fracture obtained from No. 39 in this series. "The same fracture is shown again at a higher magnification in Plate VIII., G. The crystal first broke near the shoulder of the test-piece at a stress of 13.39 tons per square inch. Fracture first took place through half the crystal by slipping on a plane intersecting the surface at about 40° to the axis of stress, the plane making an angle of about 45° to the surface. Indications of this may be seen in Plate VIII., G. The remaining half broke a few seconds later, the plane of fracture being again at 40° to the axis of stress and nearly at right angles to the surface of the strip.

Since fracture had occurred outside the gauge marks, the piece was put back in the tensile machine and again broken, this time between the gauge marks, at a stress of 14 tons per square inch and with an elongation of 84.5 per cent. The second fracture was even more peculiar than the first. Slipping took place on a plane which intersected the surface at 45° to the direction of stress and with a "dip" of about 45° . Final fracture took place upon a plane which was approximately at right angles to that upon which slipping first occurred, producing a very "blunt" knife-edge fracture. The illustration (Plate VIII., G) does not clearly show the planes taking part in these two fractures. Plate VIII., G, should be compared with Fig. 6, where four planes are indicated, but it is likely that planes II. and planes III. are in reality the same.

There were at least three planes concerned in the fractures of the crystal, but owing to distortion it is not possible to draw any definite conclusion either as to the orientation of the crystal or as to whether slip took place on cubic planes or rhombic-dodecahedral planes.

From the strips with which the authors have been working up



FIG. 6.

to the present (8 in. \times 1½ in. \times ⅛ in.) it has not been possible to cut satisfactory test-pieces in any direction other than that of the length of the strip. They consider, however, that exceedingly interesting results would be obtained if test-pieces in different directions could be cut from a single crystal. They have in process of construction a large silica tube electrically heated furnace, capable of taking sheets 6 in. \times 18 in. In sheets of this size they hope to produce crystals of a sufficient size to permit the preparation of at least two test-pieces from each crystal.

SUMMARY OF PART I.

1. Tensile tests have been made on a number of single iron crystals.

2. With a very few exceptions the tensile strength value given by large crystals was near 10 tons per square inch.

3. The limit of proportionality for a single crystal is very low—about 2 tons per square inch, or one-fourth that of finely crystalline iron. The limit of proportionality has not been found to bear any relation to the tensile strength.

4. Elongations were very variable, with a tendency in the direction of greater elongation with greater tensile strength.

5. Smaller single crystals gave more variable results for tensile strength than larger ones.

6. An account has been given of some of the types of fracture encountered in the work.

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- (2) *Journal of the Iron and Steel Institute*, 1924, No. I. p. 157.
- (3) H. C. H. CARPENTER and C. F. ELAM, "The Production of Single Crystals of Aluminium and their Tensile Properties," *Proceedings of the Royal Society*, 1921, vol. c. (A), p. 329.
- (4) *Journal of the Iron and Steel Institute*, 1924, No. I. p. 155.
- (5) H. C. H. CARPENTER and C. F. ELAM, *Proceedings of the Royal Society*, 1921, vol. c. (A), p. 338.
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- (7) *Journal of the Iron and Steel Institute*, 1924, No. I. p. 155.

PART II.

THE INFLUENCE OF CRYSTAL SIZE UPON THE TENSILE PROPERTIES OF IRON.

A knowledge of the effect of crystal size on the mechanical properties of metals is of great commercial importance. It is also of considerable academic value, particularly in connection with the study of the mechanism of the deformation of metals.

A considerable amount of research has been devoted to

the effect of crystal size on the mechanical properties of both ferrous and non-ferrous metals. Papers have been published by Arnold,⁽⁸⁾ Thompson,⁽⁹⁾ Dalby,⁽¹⁰⁾ Basset and Davies,⁽¹¹⁾ Arrowsmith,⁽¹²⁾ and Angus and Summers.⁽¹³⁾

In this section of the paper are records of a number of tensile tests which have been made on iron of a great variety of crystal sizes. Two series of tests have been made. The first series was made using iron of exactly the same composition as that used in the research recorded in Part I., since it was considered that the value of the results obtained from the single crystal tests would be greatly enhanced if corresponding results were available obtained from metal of the same composition but in the more usual condition as regards crystal size.

The second series of tests was made on material of slightly different composition from that of the first series to check the results of the first series.

Preparation of Specimens.

The first series of test-pieces was prepared from the same mild steel sheet as was used for the work described in Part I. Strips 8 inches long by $1\frac{1}{4}$ inch wide were completely decarburised by heating at 850°C . in a rapid stream of hydrogen gas for forty-eight hours. This was considerably longer than was necessary to ensure the complete removal of carbon.

The decarburised strips were then given a further annealing in hydrogen for different lengths of time at a number of different temperatures, the object of this treatment being to obtain strips in a great variety of crystal sizes.

The temperature and time for each strip are given in Table III. (p. 95). It should be noted, however, that the second heating was not always continuous. A batch of strips, after heating for some time, was cooled and a sample examined microscopically. If the crystal size was not as great as was desired, the batch was returned for a further heating. This, of course, meant that strips sometimes passed several times through the critical point (A3), each time with a refining of structure. The crystal size, therefore, is not always related to the total time of heating. This is clearly evident from the figures in Table III.

A different method was employed to produce the very largest crystal sizes. These were obtained by stressing decarburised strips until elongations of from 6 to 20 per cent. were produced, and afterwards annealing at 875°C . for twenty-four hours. In this way strips were obtained made up, in the case of the least elongation, of crystals 1 centimetre in diameter, in the case of the greatest elongation 50 crystals per square millimetre, and for intermediate elongations crystals of intermediate sizes.

Test-Pieces.

The preparation of the test-pieces from the strips was carried out in exactly the same way as was done for the single crystals. The strips were reduced to 0.110 inch thick, leaving a smooth surface finish. The finished test-pieces had a parallel portion $2\frac{1}{2}\text{ in.} \times \frac{3}{4}\text{ in.} \times 0.110\text{ in.}$, and a gauge length of 2 inches.

Method of Testing.

In all particulars the testing was carried out in exactly the same way as was described for single crystals in Part I.

Measurement of Crystal Size.

During the machining of a test-piece from a strip, a piece of metal was removed undamaged. From this waste piece two small microsections were prepared.

In Fig. 7 A represents the piece cut away during machining, B and C are the two pieces for micro specimens. B and C were

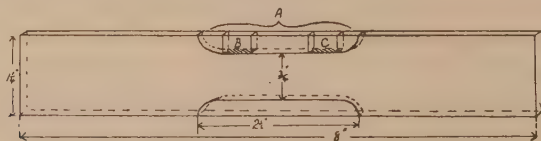


FIG. 7.

polished (on the surface indicated by hatching), etched in picric acid, and then photographed at a known magnification (generally 40 diameters). The photographs therefore represented the structure of the metal not more than $\frac{1}{16}$ th of an inch away from the parallel portion of the corresponding test-piece.

The prints were trimmed to a known size and the crystals counted (a cut crystal being counted as one-half). The number of crystals visible per square millimetre of metal surface was then calculated. The two estimates obtained for a test-piece were found to agree very well in all cases. The figures quoted in this paper are average values, and where a figure is quoted for crystals per millimetre this figure is the square root of that found for crystals per square millimetre. In some cases, to check the uniformity of crystal size, the computations were made from photographs of two microsections at right angles. This was not considered to be generally necessary, however, as no serious variations were found in the figures so obtained.

Results of Series I. Tests.

In Table III. are the tabulated results of the first series of tests. The crystal size of specimens 1, 2, and 3 is quoted as "Diameter of the Average Crystal,"* the remaining specimens as "Crystals per Square Millimetre."

TABLE III.—*Series 1.*

No. of Specimen.	Treatment to give Crystal Size.	Crystal Size. Crystals per Sq. Mm.	Limit of Proportionality. Tons per Sq. In.	Tensile Strength. Tons per Sq. In.	Elongation per Cent. on 2 Inches.
1	6% elong.	9.7	2.66	10.66	28.75
2	6½% "	7.0	2.51	11.70	30.50
3	8% "	2.5	2.85	13.66	39.50
4	10% elong.	6.3	2.89	15.03	35.25
5	12% "	15.3	2.77	16.33	47.00
6	16% "	35.6	3.69	17.05	48.75
7	20% "	48.8	4.19	17.10	50.70
8	7 days at 1000° C.	51.0	4.5	17.37	44.75
9	"	75.5	8.98	18.73	47.00
10	"	77.5	9.00	18.57	48.25
11	1 day at 950° C.	91.6	7.40	17.85	50.25
12	"	92.0	7.52	17.97	50.00
13	"	120	7.44	18.40	42.5
14	"	130	7.00	18.56	41.25
15	1 day at 900° C.	194	6.87	18.69	47.50

* The crystals being too large to be quoted as crystals per square millimetre. The diameter of the average crystal was obtained by direct measurement.

As the crystals in the specimens became smaller the limit of proportionality rose from 2.66 tons per square inch for No. 1 to a maximum of 9.00 tons per square inch for No. 10. No. 10 had 77 crystals per square millimetre. With a finer crystal size than this the "limit" was less, so that in the case of No. 15 with 194 crystals per square millimetre the limit of proportionality was only 6.87 tons per square inch.

The tensile strength for the specimen with the largest crystals was 10.66 tons per square inch—a figure very near that usually obtained for a single iron crystal. As the crystal size became smaller the tensile strength increased, until with 194 crystals per square millimetre the tensile strength was 18.69 tons per square inch.

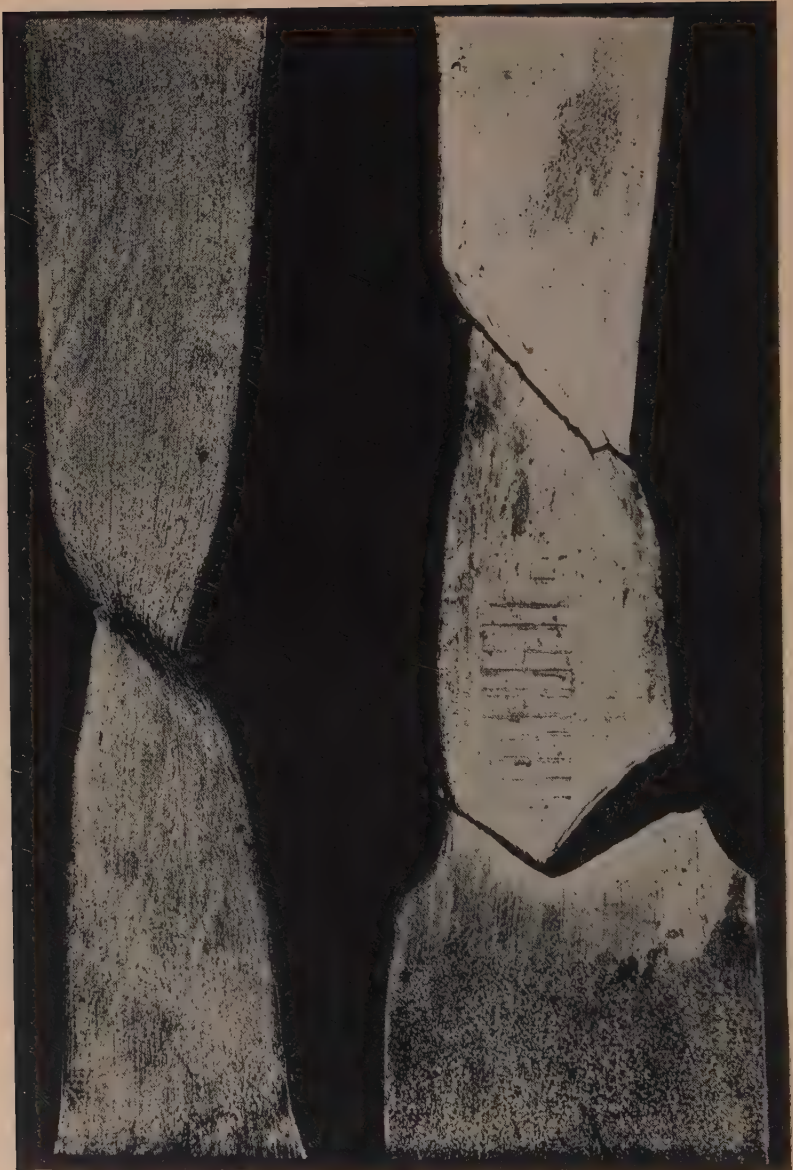
The percentage elongation on 2 inches was very low in the first four tests. This may be simply explained in the following way. Somewhere in the parallel portion of such a test-piece there was a crystal occupying a considerable proportion of the cross-section, and so oriented as to be very weak. Local contraction set in at this point and fracture occurred without any considerable general elongation. In the remaining tests (Nos. 5–15) the elongation varied from 41 to 51 per cent. The variation was due, perhaps, as much to the position of the fracture with regard to the gauge marks as to the size of the crystals in the specimens.

From the figures obtained in the tests, stress-elongation curves have been plotted which show, more clearly than the table, the effect of variations in the size of the crystals. To avoid confusion all the points obtained have not been shown in the figures, and curves have not been drawn for all the tests. Curves omitted either coincided with others already plotted, or were of an intermediate character and did not possess any new or important feature.

In Fig. 8 the early part of each test is given, using a very open elongation scale, so as to show up clearly the limit of proportionality. Each curve is numbered to correspond with the number of the specimen as given in Table III., and in brackets the crystal size is stated in each case.

It will be seen that for specimens of very large crystal size the limit of proportionality is exceedingly low. As the crystals become smaller the "limit" rises, until in the cases of Nos. 9 and 10, with





F

G

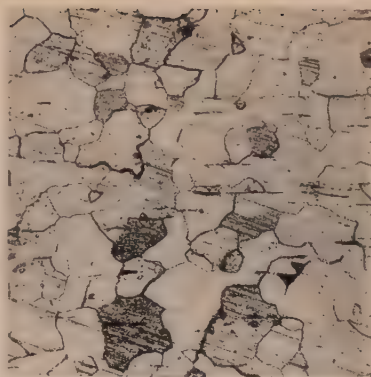
Magnified 2 diameters and slightly reduced.

A



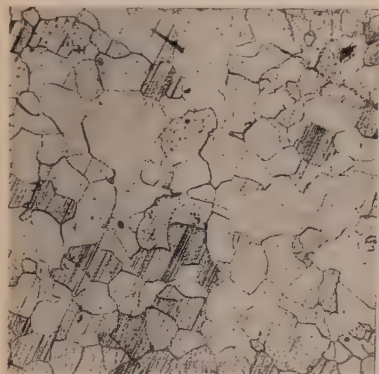
A. Test piece No. 3. Crystal size 53.
Tensile strength 17'25 tons per sq. in.
Limit of proportionality 3'42 tons per sq. in.

B



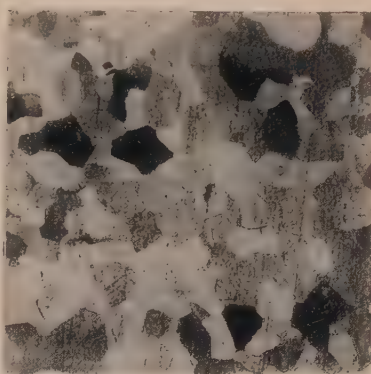
B. Test piece No. 6. Crystal size 84.
Tensile strength 17'70 tons per sq. in.
Limit of proportionality 5'42 tons per sq. in.

C



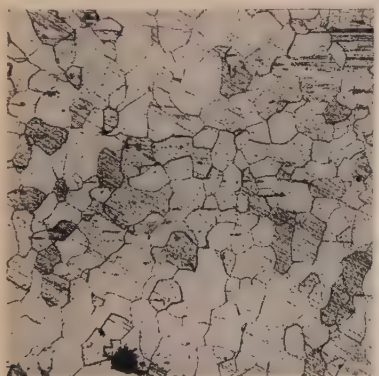
C. Test piece No. 14. Crystal size 127.
Tensile strength 19'28 tons per sq. in.
Limit of proportionality 8'70 tons per sq. in.

D



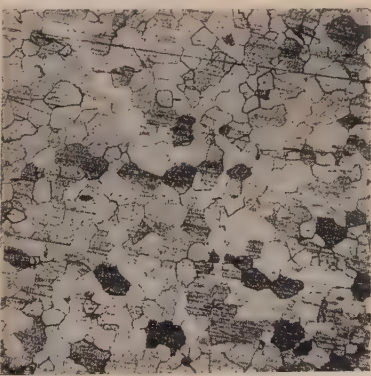
D. Test piece No. 15. Crystal size 135.
Tensile strength 19'33 tons per sq. in.
Limit of proportionality 9'92 tons per sq. in.

E



E. Test piece No. 16. Crystal size 157.
Tensile strength 19'74 tons per sq. in.
Limit of proportionality 10'08 tons per sq. in.

F



F. Test piece No. 21. Crystal size 307.
Tensile strength 17'44 tons per sq. in.
Limit of proportionality 6'17 tons per sq. in.

75 and 77 crystals per square millimetre, it exceeds 8 tons per square inch, and is not shown in the figure. With finer crystal sizes still (Nos. 11, 12, 15) the limit of proportionality is lower, being only about 7 tons per square inch.

It will also be noticed that the slopes of all curves before the limit is reached is nearly the same, indicating only very small variations in the modulus of elasticity.

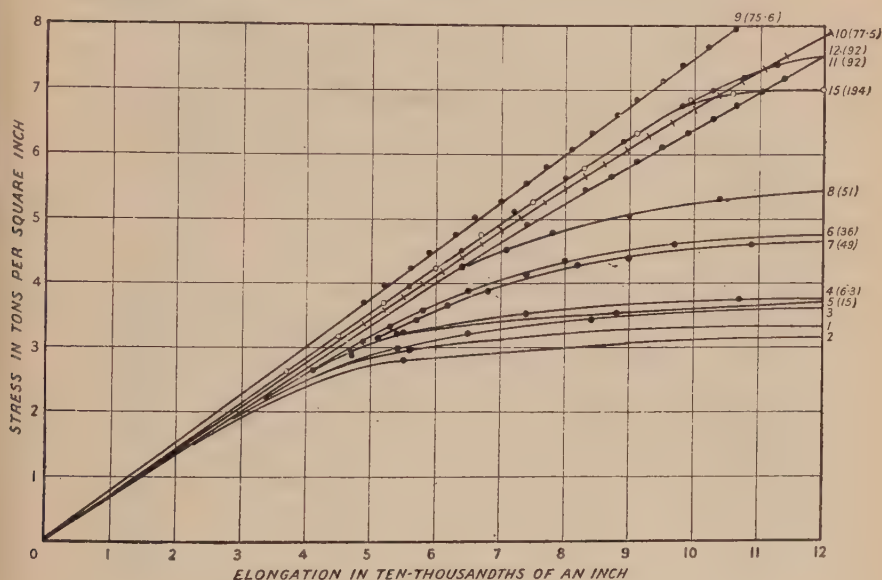


FIG. 8.—No. 1 Series. Stress Elongation Curves.

In Fig. 9 the stress scale remains the same but the elongation scale is closer, elongations being given up to 0.05 inch.

The variation in the limit of proportionality may again be seen, but the main object of this figure is to show the remarkable difference in the behaviour of the specimens at the yield point. Specimens 9 and 10 (the two highest curves) showed well-defined yield points, and the yielding continued up to an elongation of 0.03 inch. The next two curves (Nos. 12 and 15) are for specimens of finer crystal size than Nos. 9 and 10. The yield points are not so well defined, and in the case of No. 12 the yielding has not continued to so great a degree.

The remaining curves in Fig. 9 are all for specimens of a coarser crystal size than those of Nos. 9 and 10. It will be noticed that as the crystals are larger the yield point is lower and less

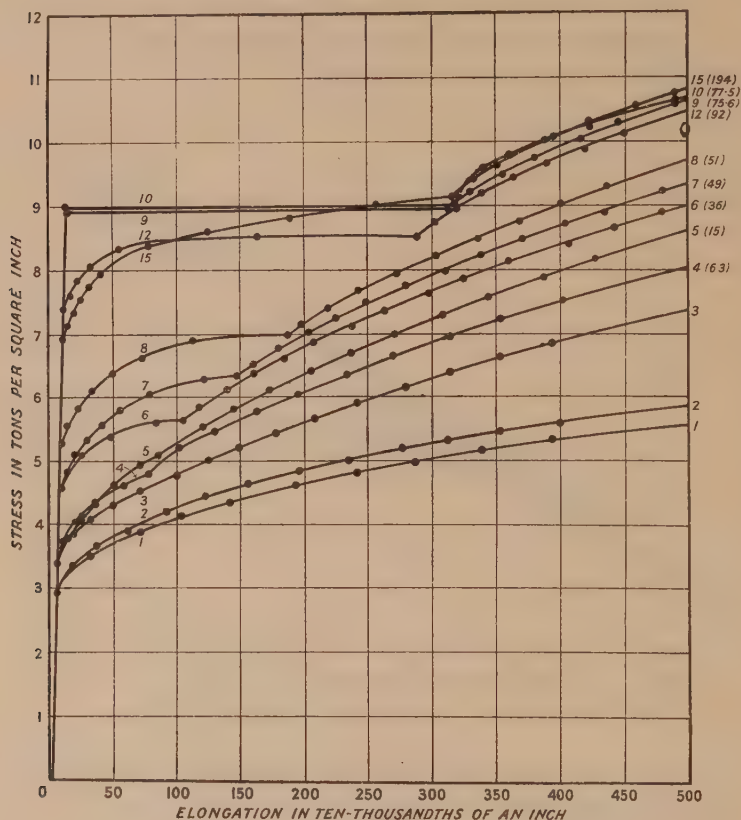


FIG. 9.—No. 1 Series. Stress Elongation Curves.

defined, and the extent of the yielding is less. In specimens with larger crystals than No. 4 (6.3 per square millimetre) there is no longer a yield point, and the curves are similar in shape to those obtained from single crystal test-pieces.

In Fig. 10 elongations are given from 0.05 inch up to breaking. The last point on each curve represents the maximum load divided by the original cross-section and the elongation after fracture. In

Fig. 10 a general increase in tensile strength with decrease in crystal size is evident, although it may be noticed that the

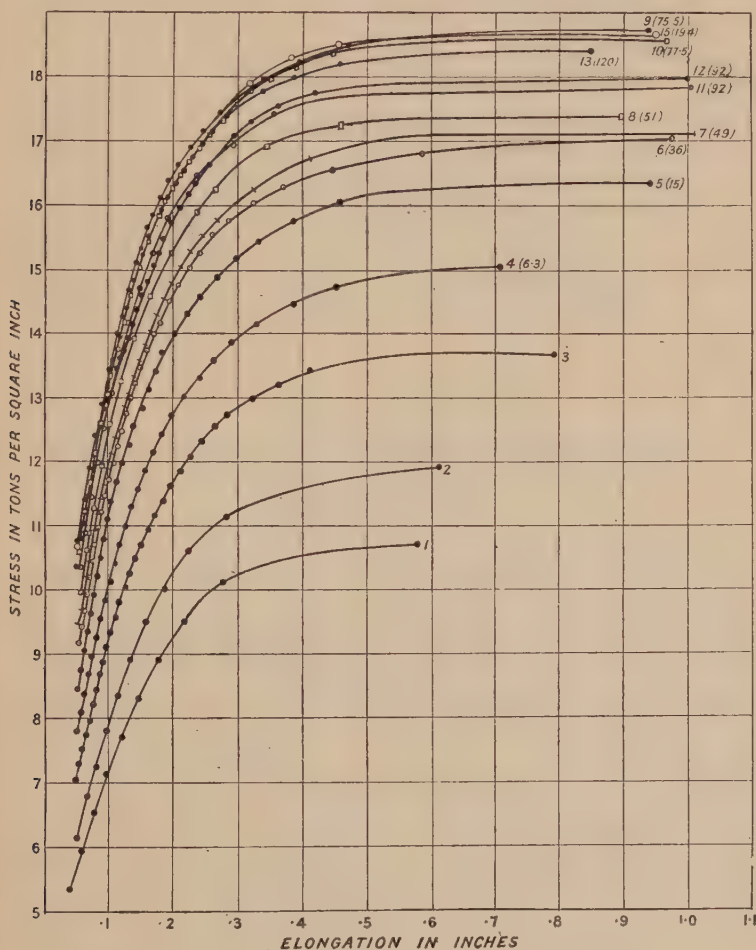


FIG. 10.—No. 1 Series. Stress Elongation Curves.

specimen of finest crystal size has a tensile strength not quite equal to the maximum.

In Fig. 11 the limits of proportionality and the tensile strengths have been plotted against crystal size. The limit of proportionality—very low with large crystals—rapidly rises to a maximum of

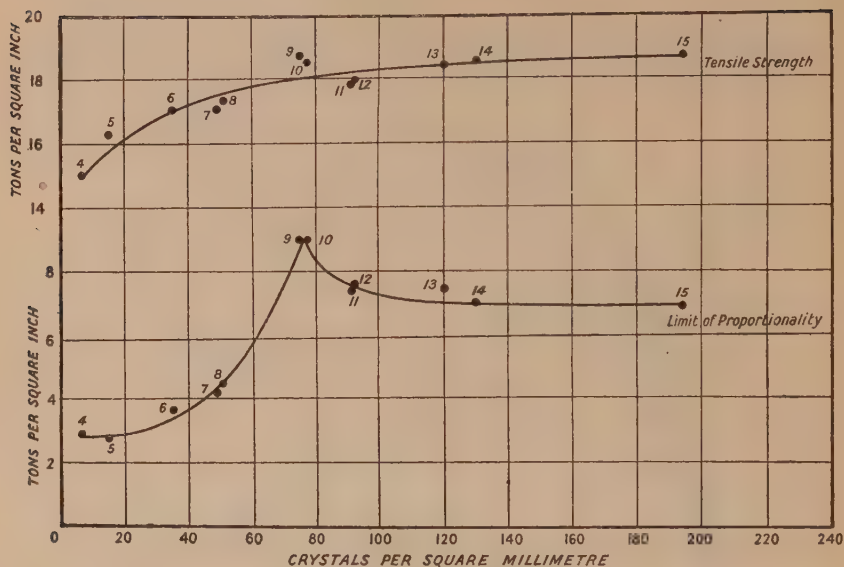


Fig. 11.—No. 1 Series.

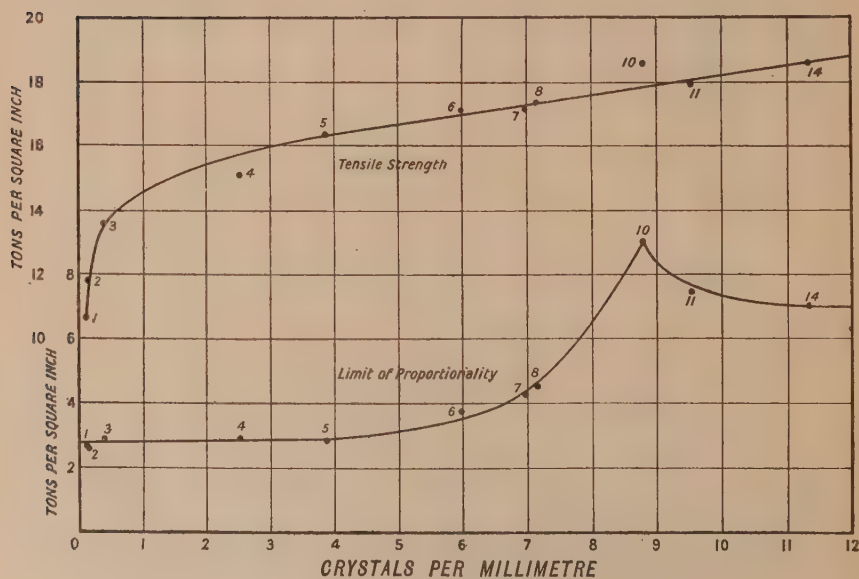


Fig. 12.—No. 1 Series.

9.0 tons at 75 crystals per square millimetre. With 90 crystals per square millimetre the limit has fallen to $7\frac{1}{2}$ tons per square inch, after which the curve remains nearly horizontal.

The tensile strength curve rises rapidly at first, but afterwards more slowly. It would be possible to draw the tensile strength curve so as to show a small maximum at the same crystal size as the maximum on the limit of proportionality curve. This, however, has not been done, since the maximum that could be shown would only be very small, and would certainly not have been shown had the limit of proportionality figures not been available.

In Fig. 12 the tensile strengths and limits of proportionality have been plotted against crystals per millimetre instead of crystals per square millimetre. The curves are similar in shape to those of Fig. 11 and do not call for any remarks.

Second Series of Tests.

The curves showing the relation between crystal size and the limit of proportionality (Figs. 11 and 12) appeared to the authors to be so remarkable that they decided to repeat the whole series of tests, using a different sheet of mild steel as the starting-point.

One important reason for this decision was that they were not certain that all their test-pieces had been cut from the sheet in the same position relative to the direction of rolling, although they believed this to have been the case. In the new series all test-pieces were cut from the sheet so that their axes coincided with the direction of rolling.

Precautions were taken to eliminate as far as possible all variables except crystal size. All test-pieces, after annealing, were cooled in the furnace at the same rate down to atmospheric temperature. The machining of the test-pieces was carried out with the utmost care, any test-piece not absolutely straight was rejected, and the greatest care was exercised during the actual testing to ensure axial loading of the test-pieces.

The mild steel sheet selected for the second series of tests was very similar in composition to that of the first series. The analysis is given below :

C.	Si.	Mn.	S.	P.
0.12	0.04	0.45	0.04	0.028

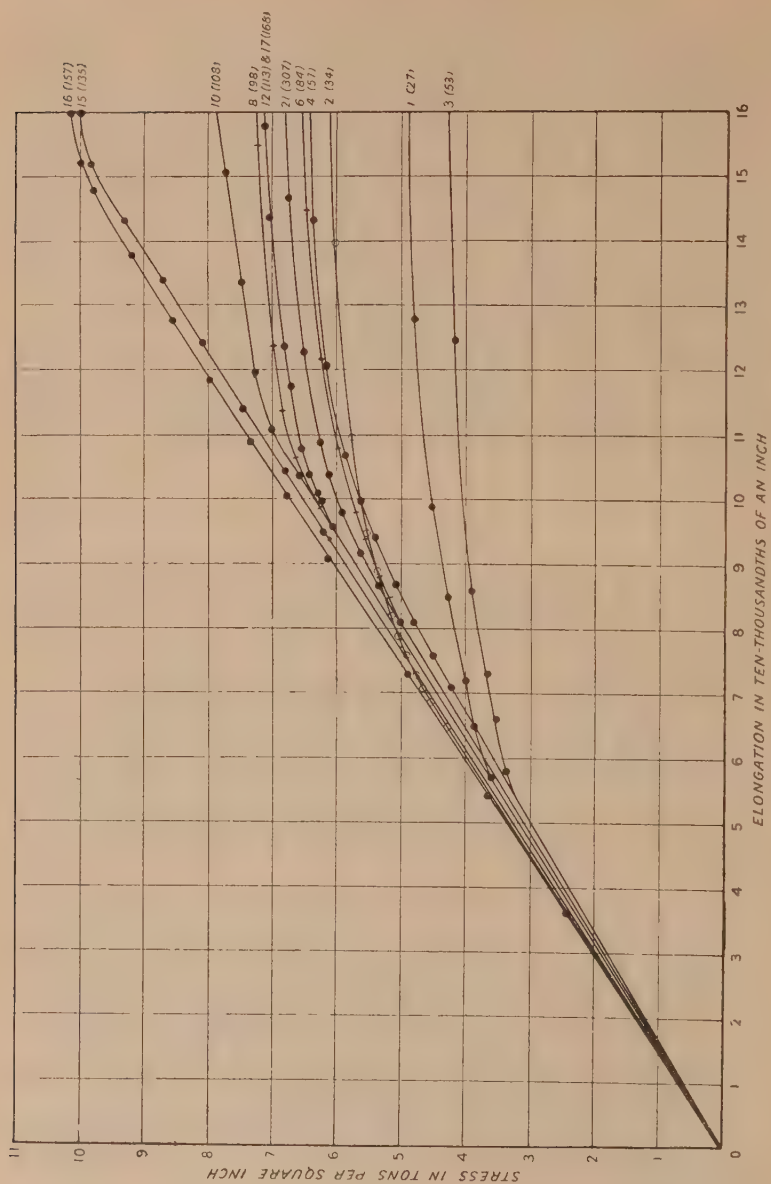


Fig. 13.—No. 2 Series. Stress Elongation Curves.

The various stages required to produce the test-pieces were carried out as before and the testing was done in a similar manner.

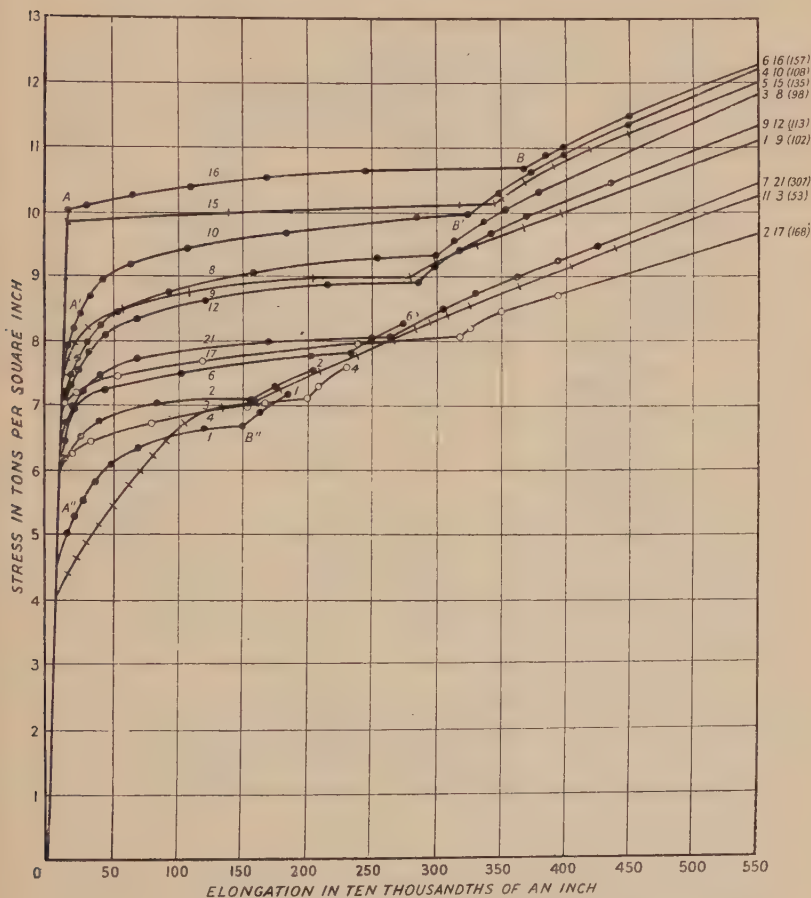


FIG. 14.—No. 2 Series. Stress Elongation Curves.

Results of Second Series.

By altering the conditions of annealing, crystal sizes were obtained from 30 to 300 crystals per square millimetre. The crystal sizes and the corresponding mechanical properties are given

in Table IV. Curves have also been drawn which correspond as regards stress and elongation scales with those of the first series.

TABLE IV.—*Series 2.*

No. of Specimen.	Treatment to give Crystal Size.	Crystal Size. Crystals per Sq. Mm.	Limit of Proportionality. Tons per Sq. In.	Tensile Strength. Tons per Sq. In.	Elongation per Cent. on 2 Inches.	Length of Yield.	Stress Difference.
1	16% elong.	27	3.77	17.21	41.25	157	3.12
2	18 „	34	4.70	17.55	41.25	170	2.56
3	20 „	53	3.42	17.25	46.25	172	3.82
4	22 „	57	4.78	16.97	38.75	201	2.80
5	168 hrs. 1000° C.	78	5.05	17.20	33.5	...	...
6	24% elong.	84	5.42	17.70	51.25	242	2.59
7	12 hrs. 1000° C.	98	6.57	18.90	46.0	255	2.84
8	36 „ 1000° C. (2 stages)	98	6.90	19.22	46.5	304	2.64
9	24 „ 950° C.	102	7.29	19.00	44.75	288	2.00
10	72 „ 1000° C. (3 stages)	108	7.07	19.80	46.25	318	3.08
11	120 „ 1000° C. (4 stages)	109	6.75	19.10	42.75	246	2.67
12	Decarb. at 1000° C. 48 hrs.	113	6.47	18.82	47.75	288	2.68
13	60 hrs. 1100° C.	118	8.05	19.22	48.5	233	1.07
14	108 „ 1000° C. (4 stages)	127	8.70	19.28	44.0	304	1.24
15	108 „ 1000° C. (4 stages)	135	9.92	19.33	45.25	337	0.30
16	156 „ 1000° C. (5 stages)	157	10.08	19.74	45.25	361	0.67
17	72 „ 850° C.	168	7.02	17.01	45.0	314	1.20
18	24 „ 850° C.	203	6.32	17.07	44.75	275	1.86
19	36 „ 850° C.	230	6.14	16.81	48.0	282	1.97
20	12 „ 850° C.	245	6.26	16.65	45.5	283	1.76
21	Decarburised only	307	6.17	17.44	48.25	260	2.06

The general similarity of these curves to those of the first series will at once be noticed.

Fig. 8 in Series 1 is similar to Fig. 13, Series 2.

„ 9 „ „ „ 14 „
 „ 10 „ „ „ 15 „
 „ 11 „ „ „ 16 „

The only figure in the second series which requires discussion here is Fig. 16. Dealing first with the tensile strength curve, a test-piece with 28 crystals per square millimetre had a tensile

strength of 17.2 tons, this being slightly higher than that obtained for the same crystal size in Series 1 (see Fig. 11). With decreasing

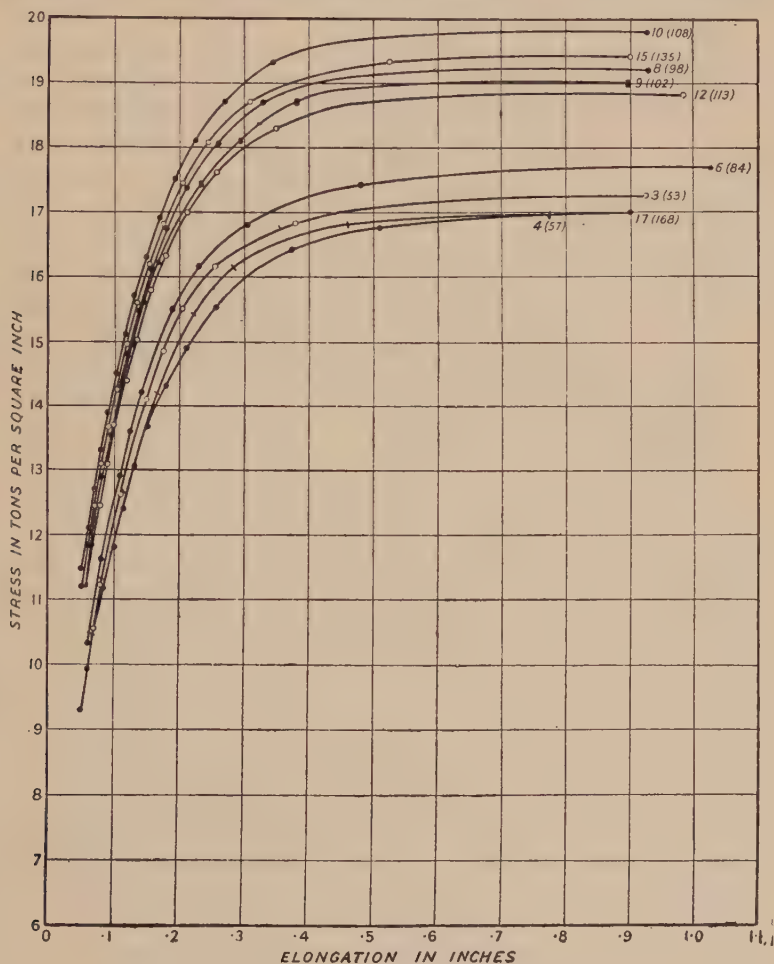


FIG. 15.—No. 2 Series. Stress Elongation Curves.

crystal size the tensile strength remained steady until about 84 crystals per square millimetre, after which the strength increased rather rapidly to about 20 tons per square inch at a crystal size of 145. With a crystal size of 166, the tensile strength had fallen to 17.0 tons, and any further decrease in crystal size had little

effect, the tensile strength of all specimens of a finer grain than 166 being about 17 tons per square inch.

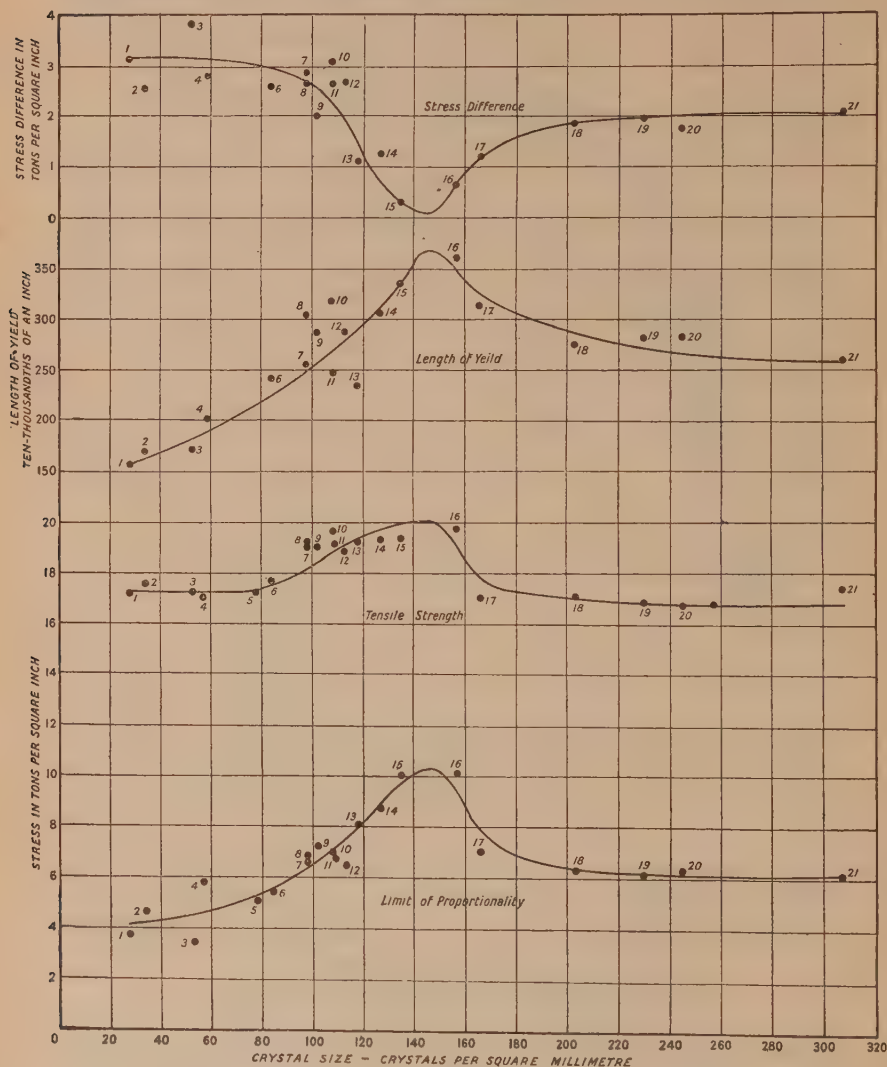


FIG. 16.

Considering now the limit of proportionality curve in Fig. 16. With the largest crystal size tested in this series, the limit of

proportionality was very low (4 tons per square inch), but as the crystal size decreased, the limit rapidly rose until a maximum of 10 tons per square inch was reached at 145 crystals per square millimetre. With still smaller crystals the limit rapidly fell to 6 tons per square inch, after which it remained constant, the finest crystal size (300 crystals per square millimetre) having a limit of proportionality of 6.0 tons per square inch.

The results of this second series show that there is a real maximum not only on the limit of proportionality curve, but also on the tensile strength curve, and that these two maxima correspond with the same crystal size. The maxima of Series 2 do not occur at the same crystal size as the maximum shown in Fig. 11, Series 1. This may be ascribed for the present to the difference in composition of the two samples of metal.

No doubt the tensile strength curve (Fig. 11) of the first series should have been drawn so as to show a maximum at the same crystal size as the maximum on the limit of proportionality curve of the same figure.

In Fig. 16 two other curves have been drawn. The lower of these represents the "length of yield" plotted against crystal size, and the upper the difference between "stress at limit of proportionality and stress at end of yield." The length of yield is taken as the difference between the length of the specimen when the limit of proportionality is reached, and the length of the specimen when a stiffening of the material occurs showing as a break in the stress elongation curve. In Fig. 14 the length of yield is the horizontal distance between A and B, A' and B', &c. The vertical distances between A and B, A' and B', are the values plotted for stress difference.

The curve of stress difference shows a minimum, and the curve of yield length a maximum at the same crystal size as the maxima on the limit of proportionality and the tensile strength curves. The authors do not feel prepared to discuss the significance of the stress difference and yield length curves, but they have been shown in Fig. 16, as additional evidence of a discontinuity of properties with change in crystal size.

Consideration of Results.

The authors are unable to offer an explanation of the discontinuity of properties which they have found. It seems desirable, however, to discuss some possible causes of the discontinuity.

First of all, it is possible that the prolonged heating of the iron in contact with hydrogen is the cause of the phenomenon. Exceedingly low-carbon steel becomes brittle when it has been heated in hydrogen, especially when the manganese content is also very low. The steel sheets used in these experiments were neither very low in carbon originally nor were they very low in manganese, and certainly no sign of brittleness was ever detected.

A series of experiments was carried out using a nitrogen atmosphere instead of a hydrogen atmosphere during the annealing to cause variations in crystal size. These experiments were entirely negative, showing no difference in the mechanical properties whichever gas was employed.

Two variables which may be the cause of the discontinuity are: (a) Variations in the shape of the crystals, and (b) the relation between maximum and minimum crystal size to average crystal size—that is, uniformity of crystal size. A note of great interest in this connection has been published by Gulliver,* in which it is shown that prolonged annealing tends to decrease the uniformity of crystal size.

A few tests have been made on specimens made up of unusually shaped crystals. By taking a very coarsely crystalline specimen and heating it to 950° C. and quenching in water a much finer crystal size is obtained. By reheating for thirty minutes to 875° C. any hardening effect of the quenching must be removed; the structure of the metal now appears as small crystals with very uneven boundaries. Specimens so treated give higher values for the limit of proportionality and tensile strength than might be expected from considerations of average crystal size.

In addition, if the reheating be continued for some hours, a considerable fall in mechanical properties results, although only very small changes in average crystal size occur. An examination of microsections leads to the suggestion that the area of crystal

* G. H. Gulliver, "On Grain Size," *Journal of the Institute of Metals*, No. 1, 1918, p. 145.

boundary decreased without a decrease in the number of crystals.

During the progress of this research a number of specimens have been obtained where the crystal size was obviously very far from uniform. Such specimens were set on one side. In order to obtain some insight into the effect of a non-uniform crystal size, some of the pieces have since been tested. The results indicate that, when the average crystal size is the same, a uniform crystal size gives lower results than when the crystals are not uniform in size.

In Table IV. it may be seen that specimens of small crystal size were obtained by annealing below the critical temperature A_{c3} , and these all had rather low mechanical properties. Those of intermediate crystal size, which included pieces with high values and low values for limit proportionality and for tensile strength, were all obtained by annealing above A_{c3} in one or more stages. It is difficult to come to any conclusion as to whether the actual annealing temperature—apart from the crystal size so produced—has any effect upon the properties, for the treatments employed were complicated. These complicated heat treatments were mainly due to efforts being made to produce certain crystal sizes, these efforts being very often unsuccessful.

The various factors which govern the growth of crystals after recrystallisation in pure, or nearly pure, iron are by no means well understood. Great difficulties have been encountered in this work in obtaining certain desired crystal sizes. What appeared to be the same treatment given to two similar specimens did not always result in the same crystal size. The undesired production of columnar crystals of a very large size was perhaps the greatest difficulty encountered.

A number of photographs (Plate IX., A to F) have been included to illustrate the structures of some of the specimens tested. The magnification in every case is 40 diameters. A represents material of fairly coarse crystal size, and the figures are arranged in order of decreasing crystal size, F being the finest tested. The specimen number, the crystal size, and the mechanical properties are quoted beneath each figure.

The authors think that it will be agreed that, apart from the average crystal size, there are no important differences between

the structures shown. Taking into account the various factors which have just been briefly discussed, the authors have come to the conclusion that average crystal size is the variable which is the cause of the different mechanical properties found in the material tested.

A great deal more work will be necessary before a complete understanding is attained of the relation between the mechanical properties and the structure of iron. The authors feel justified, however, in publishing the results so far obtained because of their value in connection with the single crystal tests.

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Iron and Steel Institute.

THE ORIENTATION OF CRYSTALS
PRODUCED BY HEATING STRAINED IRON.

BY C. F. ELAM, M.A. (LONDON).

IN describing experiments on large crystals produced by annealing strained iron Professor Edwards and Mr. Pfeil¹ noticed that square etching pits were frequently obtained with a diagonal in the direction of straining, and from this and other observations they formed the opinion that there was a similarity of orientation of the crystals. Professor Edwards has kindly given the author several



FIG. 1.

crystals for X-ray examination, and the crystal axes relative to the axis of the strip, *i.e.* the direction of straining, of ten crystals have been determined. Some of these were determined by Mr. R. L. Aston at the Cavendish Laboratory, Cambridge, who has kindly allowed his results to be included here. The method of depicting the axis of a specimen relative to the crystal axes has already been described.² Fig. 1 represents part of the stereographic projection

¹ Edwards and Pfeil, *Journal of the Iron and Steel Institute*, 1924, No. I. p. 129.

² Taylor and Elam, *Proceedings of the Royal Society*, 1925, vol. cviii. (A), p. 28.

of the crystal axes with the positions of all axes of the test-pieces, and hence the direction of straining, marked by a point. The relation of each point to the three principal crystal axes, *i.e.* the apices of the spherical triangle marked (100), (110), and (111), indicates the orientation of the crystal. The diagram shows that the points are scattered throughout the triangle and that the orientation of the crystals is consequently very varied.

Only two crystals showed cubic etching pits, and in both of these the surface of the strip was parallel to a cubic (100) plane in the crystal. These crystals began to show pits very quickly on etching in dilute nitric acid, while other crystals appeared quite unattacked. The pits were somewhat like indefinite-shaped pyramids at first (Fig. 2, Plate X.), but on prolonged etching became square, similar to those frequently found in iron. Crystals of other orientations only showed pitting on prolonged etching, and although the form varied from crystal to crystal, the pits had no regular shapes. This applied even when there was an octahedral plane parallel to the surface of the specimen. In Fig. 3 (Plate X.) are shown two crystals, one of which is deeply pitted and has a cube face (100) nearly in the plane of the section. The other is attacked more uniformly, and X-ray examination showed that the plane of the section was approximately a (112) plane. It is interesting to note that in a body-centred cubic lattice, of which iron is an example, this plane is one of those thickest in atoms. It is also interesting to note the differences in the appearance of the scratches on the two crystals, indicating a difference in hardness.

From these experiments it appears that crystals produced in iron by this method have not necessarily the same orientation, but that it should be possible to pick out those in which a (100) plane lies in or near the plane of section. The etching effects on other planes are not sufficiently definite to enable their crystallographic position to be determined.



FIG. 2.

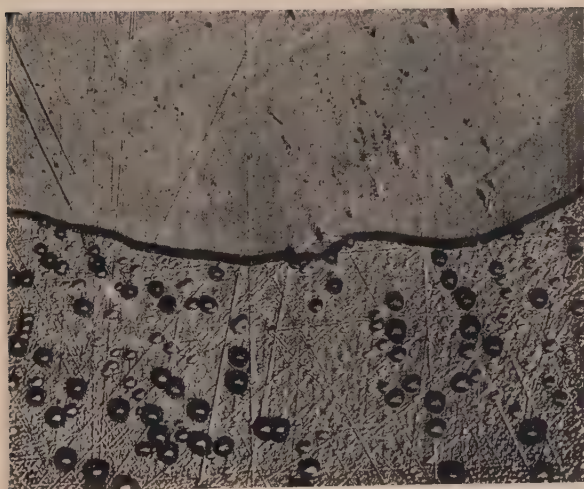


FIG. 3.

DISCUSSION.

Miss C. F. ELAM (London) desired to make a few remarks in regard to the paper by Professor Edwards and Mr. Pfeil. She was very anxious to work out completely the distortion of the iron crystals as she and Professor Taylor had already done in the case of aluminium. There was no doubt that by distortion measurements and X-ray measurements it would be possible to determine both the slip-plane and direction of slip. In one crystal already obtained from Professor Edwards and Mr. Pfeil there were so many possible slip-planes equally inclined to the axis that it appeared to have slipped on different planes in different parts, so that uniform distortion was not obtained. She had started experimenting with another crystal and hoped that more successful results would be obtained; meanwhile, it was unwise to speculate too much while awaiting them. She desired to point out that the only experiments that had been done with a body-centred cubic lattice were by Dr. Goucher, who worked out the distortion of tungsten, and he found that slip was usually on a (112) plane in a (111) direction, except in one case where there were rather exceptional circumstances in which it occurred on a (100) plane in a (100) direction. Slip on dodecahedral (110) planes was not observed, but in the crystal which she had examined there certainly were slip-bands corresponding to those planes. The authors stated that they expected slip to occur most readily when two dodecahedral planes were at 45° to the axis of stress, *i.e.* on the planes of maximum shear. Goucher found with tungsten that the normal position was 40° to the axis and 35° when it was slipping on two planes. The tangential component of stress was given by the formula:

$$S = \frac{T}{A} \cos \theta \sin \theta \cos \eta$$

in which T = total load on the specimen;

A = area of cross-section of specimen;

θ = angle between normal of slip-plane to axis of specimen;

η = angle between the projection of the axis of the specimen on the slip-plane and a possible direction of slip.

The direction of slipping was not necessarily in the direction of greatest inclination, and must be taken into account in calculating the shear stress. She desired to ask the authors whether they calculated the breaking stress on the original or on the final cross-sectional area of the specimen. Her experience with many crystals was that they were quite as strong as small crystal material, because they pulled out very much more, and the cross-sectional area was thereby reduced and the increase in hardness due to the extension was also greater. Their breaking stress sometimes exceeded that of the small crystal material.

Professor H. C. H. CARPENTER, F.R.S. (Member of Council), observed that the authors' work had brought them to some extent into association with Miss Elam's experimental work on the determination of the orientation of single crystals. He did not propose to deal with that aspect of the investigation, because it had already been dealt with fully by Miss Elam in her remarks. If, however, he might offer a word of advice to the authors, it was that they should, if possible, take up X-ray methods of investigation in connection with their work. It was the experience of Miss Elam and himself that it was impossible to draw conclusions about the orientation of single crystals without determining those experimentally by X-ray analysis. It was not easy work and it took some time to learn, but it was absolutely essential.

He proposed in the course of his remarks to deal with a few other points in the paper. He noticed that in all cases the single crystals of iron produced were covered with a film of fine crystals which had to be removed by filing. He gathered from the paper that the authors had tested the crystals in that condition, but in order to put the point specifically he would like to ask whether they polished any of the filed crystals and tested them in that condition, or whether they were tested as filed. The curves shown in Figs. 1 and 2 were very interesting, because they showed for the first time, as far as he knew, that a stress elongation curve of pure iron could be obtained without a yield point. As the authors said, in that form the iron behaved like a non-ferrous metal such as copper. Whether that would be regarded as an advantage from the point of view of the Institute time only would show. He thought a provisional conclusion might be drawn (particularly as it was borne out by the very interesting curves shown in Fig. 14, where the gradual development of a yield point was seen as the crystal size diminished), namely, that the yield point of iron was a property connected with the boundaries of the crystals, and was not a property of the iron crystal itself. If the authors had any opinions on that point, he thought it would be of interest to the members if they would state them, but, at any rate, it seemed possible to draw provisionally the conclusion he had mentioned.

He desired in the next place to say a word about the figures given for limits of proportionality in Table I., which varied somewhat, but had an average value of rather over 2 tons per square inch. He was not prepared to say that those figures were incorrect, but he thought they might be too high. The reason he said that was that the authors had tested crystals after having filed them. That would produce some local distortion and hardening, and the effect of that would be to raise the limit of proportionality. Some years ago Miss Elam and he had obtained figures of the limit of proportionality of single aluminium crystals which they had never published, because they were not sure that the metal had not been hardened by distortion, although every care had been taken to prevent that happening. It was rather interesting that their figures for aluminium were similar to the authors'

figures for iron in the sense that the limit of proportionality was about the same proportion of the ultimate stress in both cases. In the authors' paper it was about one-quarter, whereas in their experiments with aluminium it was about one-fifth. The absolute values were of course lower in the case of aluminium, as it was a much weaker metal. There was, however, a difference between the two metals as regarded the values of ultimate tensile strength. Those varied considerably in the case of aluminium, whereas nineteen out of twenty-five single iron crystals referred to in the paper had a tenacity of 10 tons per square inch. It was clear, therefore, that that was the value which tended to be produced when single iron crystals were prepared in that way. It seemed to him probable that the variations in percentage elongation were connected with differences in original orientation in spite of the similarity of ultimate stress values. He gathered that that was also the authors' view, since they stated that the ten crystals referred to in Table I. had pulled out in three different ways—probably the first seven in one way, the next two in another way, and the last one in still another way.

He would like to ask the authors whether they had made any experiments to produce single crystals in either round or square bars. Miss Elam and he had found much greater variations in the method of distortion of single crystals tested in strip form than in the case of round and square bars. He was inclined to think that a more normal type of fracture was obtained with either round or square bars, and if the authors could prepare single crystals of iron in either of those forms and test them, he thought the results obtained would be very interesting. He was glad to notice that the authors were contemplating the preparation of still larger crystals in sheet form which could be tested in more than one direction.

Miss Elam's Note on "The Orientation of Crystals Produced by Heating Strained Iron" was a valuable supplement to the paper by Professor Edwards and Mr. Pfeil. Its great value was that it gave definite experimental evidence with regard to the orientation of the single iron crystals. She had been able by that method to prove that, when the cube face lay in the plane of the specimen, cubic etching pits were obtained in that and in no other position. That accordingly was a simple method of testing where, in any given case, the cube face was in that position. Further work of that kind on the orientation of the single iron crystals was required, but it was clear that the single crystals produced in iron by the method of straining and heating did not necessarily have the same orientation.

Sir WILLIAM ELLIS, G.B.E. (Past-President), said that he did not intend to attempt to discuss the papers, but wished to remark that during the past year, while he was President of the Institute, it was his duty and pleasure to visit the South Wales Institute of Engineers. He need hardly say that he was very kindly received by them, and part of the arrangements consisted in a visit to the University College,

Swansea. He was very glad to find that the Iron and Steel Institute was receiving the results of original work from that source. He attached the utmost importance to the efforts of Professor Edwards and his colleagues in that comparatively new centre, which was one of great importance; and he thought the effect of such original work as that under discussion could not fail to be a help to that growing technical institution, which he hoped some day might become a university.

Professor C. H. DESCH, F.R.S. (Member of Council), thought the work on single crystals was the most important of all the researches now in progress concerning the fundamental behaviour of metals, and the facts brought forward in the paper were particularly interesting. Referring to the curves in Fig. 1 showing that the single crystals gave no indication whatever of the yield point, he thought it had become pretty clear that the yield was due to the rapid transfer of stress from one crystal to another over a considerable group. Many of those present had heard Professor Jenkin lecture on his theory of fatigue and had seen his very interesting model, by which he was able to produce a most excellent stress elongation curve with a very distinct yield point, due to the sudden yield of one crystal throwing stress on to its neighbours. The repetition of the process several times gave the peculiarly jerky form which was found in most autographic stress records of metals having a yield point. One would expect the elastic limit of a single crystal to be extremely low, and even in the ordinary specimens consisting of a very large number of crystals, he thought it was certain that when stress was applied some of the crystals yielded at some such limit as that. In the work on brasses and nickel done in his laboratory some time ago by Mr. Handford, using a heterodyne arrangement of wireless valves to detect slip, it was found there was actual yield of individual crystals in the mass at stresses below 2 tons to the square inch. The yield of a single crystal caused such a redistribution of stress that other crystals were able to take it up, and no effect large enough to be shown on an ordinary stress curve appeared until a much larger value was reached. The elastic limit was, then, the point at which a considerable number of crystals had given way, and the true elastic limit of any single crystal was a very much lower value indeed. In regard to the appearance of the line of slip at angles of 45° , as Miss Elam had pointed out, 45° was not necessarily the direction along which slip would occur. He thought it was generally recognised in memoirs on the deformation of solids that where a tensile stress was applied one might expect the slip to occur at about 40° and not at 45° ; and in some work published by Mr. Adcock through the Institute of Metals some time ago on cupronickel, it was found that the principal slip occurred in many crystals at an angle of about 40° . When an ordinary test-piece was being strained, the Lüders lines appeared, not at 45° but at 40° , and it would be of great interest to determine the actual faces on which slip occurred.

If it should prove to be not a cube face for iron it would be very remarkable, since there was no doubt that chemical action did proceed along the cube face. It might be mentioned that the (112) face which Miss Elam had already referred to was of great importance in connection with iron, because that was the face along which Neumann's lines were formed in meteorites and similar masses of iron. He also thought Miss Elam's Fig. 3 showing the great difference between the two faces exposed was of very remarkable interest. It was known that on etching ordinary specimens some crystals would generally etch very much more than others; and that figure was a particularly striking example, showing also that there must be a considerable difference of hardness, as indicated by the scratches.

Dr. F. JOHNSON (Birmingham) said that he desired to support the suggestion made by Professor Carpenter that round bars of large crystals would give interesting results; they would be preferable because they were easy to prepare and to load axially while testing. He was very much interested in the curve shown in Fig. 16, in which a maximum yield was shown for an intermediate grain-size. In some work on copper which he did a few years ago he did not find a maximum yield point for intermediate grain-size, but he did find a maximum percentage elongation. With regard to specimen G on Plate VIII. and the very much higher tensile strength obtained in that specimen, it had occurred to him that the cessation in the loading, and the necessity for reapplication of the load, might have allowed some change to take place in the resistance to tension of that nameless material which existed on the planes of slip. He thought the authors were diffident at being able to obtain large crystals in plate or sheet form which would enable them to carry out trials conformable with those required in practical testing to ascertain the stamping and cupping qualities of steel sheets. He looked forward to the day, however, when they would succeed and give some explanation of the great differences which were obtained between the various grain-sizes of materials in that class of work. With regard to Miss Elam's paper, the photomicrograph on Plate X., Fig. 3, showed etching pits in one crystal and not in another. The author suggested that the pitted crystal was softer than the other one, because it showed many more scratches. Was she quite sure that the flowed layer on the plain crystal had been entirely removed, and that further etching might not complete its removal and show scratches underneath it, indicating that there was not that difference in hardness which she assumed?

Professor C. O. BANNISTER (Liverpool) said he desired to make a few remarks on the curves shown in Figs. 11, 12, 16. Those curves were obtained from experiments on two different sheets, and they were very similar, but showed maxima at different positions. He suggested that there was insufficient evidence at the present time to consider those

maxima seriously. He was glad that the authors made the second series of experiments on a different sheet, because if they had ended their paper on p. 101 with the results obtained on the first sheet only, the erroneous conclusion would have been arrived at that those maxima were obtained in sheets giving 76 crystals per square millimetre. After carrying out their work with the second sheet the authors obtained the maxima at 160 crystals per square millimetre, and ascribed the variation for the present to the difference in composition of the two samples of metal. On comparing the analyses given he found the differences were very small: carbon 0.01 per cent., silicon 0.017 per cent., manganese 0.01 per cent., sulphur 0.012 per cent., and phosphorus 0.008 per cent.—all somewhere near the limits of error of determination of those elements.

It was a very curious thing that the results for the two sheets could actually be used to demonstrate the exact opposite to that which the authors had set out to prove, namely, that the size of the crystals was of comparatively little importance, but that similar results were obtained from specimens which had been treated in a similar manner. If specimens from Tables III. and IV. which had received the same treatment were compared, it would be found that although the crystal sizes varied in three cases by 25 per cent., 14 per cent., and 50 per cent., the results showed greater similarity than was obtained by the comparison of specimens of the same crystal size. In the next place, it would be found possible to divide the results in Tables III. and IV. into three groups: first, those obtained by stressing decarburised strips and annealing at 875° C. for twenty-four hours; secondly, those obtained by heating the decarburised strips at 1000° for different lengths of time; and, thirdly, those obtained by heating decarburised strips to lower temperatures of 850° or 950°. If the results obtained for those three groups were compared separately, it would be found that there was very much closer agreement than if a comparison were attempted based on the size of the crystals only. By comparing the figures in that manner it was found that the maxima occurred in the two curves in the specimens that had been heated to 1000°. Again, if specimens 9 and 10 were taken from Table III. and specimens 15 and 16 from Table IV., it would be found that almost exactly the same results were obtained throughout, in spite of the fact that in the first two there were 75.5 and 77.5 crystals per square millimetre, and in the second two 135 and 157 crystals per square millimetre. From that examination of the authors' results he had come to the conclusion that the method which at present had to be used for the preparation of the crystals of different sizes were too complicated; and also that in comparing results of tests with the number of crystals, it would be absolutely necessary to use a uniform method for the preparation of the different specimens. When it was possible to get a series of tests from specimens prepared in a similar manner all the way through, he thought greater uniformity would be obtained and no maxima would be present.

Professor C. A. EDWARDS, in reply, said that, on behalf of Mr. Pfeil and himself, he desired to express very keen appreciation of the welcome that had been given to the endeavour put forward in the paper. It would not be possible to reply in detail to all the questions that had been raised, but he would touch on those which seemed to be of most importance. All the points that Miss Elam referred to were extremely interesting, and appeared to indicate a somewhat different point of view from that of the authors. The actual difference between them, however, was not quite so great as might at first sight appear to be the case. The authors were inclined to think that, with very large crystals, there was a plane which had an angle of 45° in relation to the axis of the crystal, which was fairly constant. They only considered that to be the case, however, when the crystals had been grown to, say, their particular maximum degree. In the special case that Miss Elam referred to, in which she tested the crystals on one specimen, the authors would not expect to find a similarity such as they suggested with very large crystals, and he thought that that, to some extent, eliminated a very large proportion of the apparent difference of opinion. He particularly wished to thank Professor Carpenter for his very kind remarks. Lest a slight misconception should arise in connection with one observation that Professor Carpenter made in regard to the similarity between non-ferrous and ferrous metals, he would like to stress the point that that similarity was not carried beyond the absence of a yield. There was a definite limit of proportionality in iron somewhere about 2 tons per square inch, whereas in copper and such other metals there did not seem to be any limit of proportionality, so far as the authors knew. He thought Professor Carpenter was quite right in saying that, in all probability, there was more or less definite relationship between the percentage elongation and the orientation, and, at first sight, that might appear to give rise to the conclusion that their view in regard to the similarity of orientation was wrong. But he did not think that was the case when the point was followed to its ultimate conclusion. The authors considered that one plane was at 45° to the axis of the specimen as it had been prepared; but, of course, the degree or distance of possible slip on any such plane, with a specimen such as they were using, would vary in accordance with the relation of the plane to the surface of the specimen. The area of a plane might vary, but, whilst varying, it did not alter the angle in relation to the axis of stress such as the authors referred to; it would, however, have an effect on the extent of elongation or the extent of slipping. Both Professor Desch and Professor Carpenter had suggested that it would be more important or, at any rate, extremely useful to them to have tests on single crystals in round or square bars. Mr. Pfeil was extending the work, and had gone some considerable distance in that direction. He had been able to produce bars with single crystals running through the section, but they had not yet cultivated the habit of growing to any great length.

The authors agreed with the statements of Professor Carpenter and Professor Desch with regard to Part II. of the paper relating to the effect of the size of the crystal determining the yield point, *i.e.* a boundary effect being the true explanation. He thanked Sir William Ellis for his very kind remarks, which would be appreciated, not only by the authors, but by all those who dwelt in South Wales.

In reply to Dr. Johnson's observations, Professor Edwards reiterated the opinion of the authors that the rather high values given in ultimate tensile stress for specimen G were probably due, as they tried to indicate in the paper, to the possibility of the plane of a crystal in that specimen being at a different angle from the large majority of the specimens tested. The authors would like to have big crystals of the kind referred to, and they intended to try to obtain them. He was glad to say they had a furnace which would take a sheet of something like 24 inches by 18 inches, but whether they would be able to obtain a crystal of that size or not remained to be seen. He now wished to turn to what appeared to be a very severe criticism of the paper—namely, that which had been put forward by Professor Bannister. To some considerable extent he agreed with what Professor Bannister said. Possibly when the authors were able to carry the work further it might be found that the maxima were rather misleading; but he desired to emphasise the fact that with the evidence before them the authors could not possibly have neglected them. If they had drawn a curve, neglecting to draw maxima, he thought they would have left themselves in a much more difficult position from the point of view of discussion than they had done at the present time. They certainly did say that probably the difference in the position of the maxima in the two series might conceivably be due to a difference in the composition of the two samples, but they quite intentionally did not commit themselves to whatever they thought the difference might be. He did not think it would be due to the slight difference of manganese or of phosphorus, and as the carbon had been removed that could not possibly come in. But there were still other things to be considered, such as the original oxygen content of the steel, which had been either partly or completely removed by annealing in hydrogen, so that he did not think they need go any further in that connection. There was more than an element of truth in Professor Bannister's criticism as to what the authors were really testing. He confessed that they had indicated the data and discussed them in relation to crystal size, but they had also to admit that in order to produce those differences of crystal size they had been unfortunately compelled to adopt different methods of heat treatment. Whether the results obtained were entirely due to the differences of crystal size, or whether they were also partly due to the difference of heat treatment, which had been necessary in order to produce the difference of crystal size, the authors could not say. More work would be necessary before they were able definitely to answer that, because heating in hydrogen to different temperatures might have a different effect in relation to removal of oxygen. He

would like, however, to draw attention to one point which Professor Bannister did not seem to have observed when he classified the results into three groups. Professor Bannister suggested that the mechanical properties seemed to depend more on the temperature to which the specimens had been treated than on the crystal size. If reference were made to specimen No. 5, which fitted on the curve, and specimen No. 16, which also fitted on another section of the curve, it would be seen that they had both been heated to $1000^{\circ}\text{C}.$, but one gave an ultimate breaking load of 17.2 tons and the other of 19.74 tons. Further, the length of time to which they had been heated to that temperature was very nearly the same, being 156 hours in one case as against 168 hours in the other. In order to produce a difference of crystal sizes in those instances, it was necessary to pass through the critical point a different number of times. Therefore on examining results obtained from those two specimens it certainly looked as though the effect was due to crystal size.

CORRESPONDENCE.

Mr. E. ADAMSON (Sheffield) wrote that there were one or two points concerning which some of the members would be glad of an explanation from the authors. On p. 80 it was stated that at the end of the operation of filing all the crystals had the same uniform thickness. Did the authors mean the same thickness on a cross-section of the test-piece after the specimens were prepared by heat treatment given, or did that heat treatment produce crystals which were as large as the section of the test-piece, namely, 0.11 inch? Further, were the crystals shown on the photomicrographs on Plate IX. the crystallisation of the test-bars before or after heat treatment?

There had been so much adverse criticism amongst practical men of wide experience as chemists and metallurgists regarding the tests of limits of proportionality, and, as possibly there was some misconception in that respect, would the authors give their definition of the terms "elastic limit" and "limits of proportionality," and state what was the advantage of the latter over the former?

In America, in particular, there had been a great discussion on the test of limits of proportionality, and the American mills—no doubt at the instigation of the American Society for Testing Materials—would not tolerate that test, as being too expensive and of no practical value.

The AUTHORS wrote, in further reply to Miss Elam, that the tensile strength figures were calculated on the original area, as stated on p. 82. Owing to the fact that the majority of the crystals pulled out to a knife-edge at the fracture, it was useless to attempt to obtain a figure for breaking stress.

Professor Carpenter was correct in saying that the crystals were

filed in all cases and were tested without polishing. In spite of the fact that the filing was carried out with the utmost care, there was, no doubt, some local hardening which would have an effect on the results. The authors considered, however, that the inaccuracy due to the hardening was of less importance than the experimental errors in the measurement of stress and strain. Some work since carried out by Mr. Pfeil indicated that slip lines appeared on the surface of strained crystals at lower stresses than those given in the paper for the limit of proportionality and elastic limit.

Professor Desch appeared to think that the authors had found slip lines at 45° to the axis of stress. That was not the case. The authors had found cubic cleavage planes at 45° to the axis of stress.

In reply to a written comment from Dr. Johnson the authors would point out that specimen G, Plate VIII., had not an appreciably higher tensile strength, due to the cessation of loading; as stated in the paper, it first fractured at 13.39 tons per square inch, and after restressing at 14.00 tons per square inch. Both those figures were very much greater than those usually obtained.

In reply to Mr. Adamson, the authors wrote that when a large crystal was grown in an iron strip by that method it occupied the whole of the cross-section of the strip, except for a thin surface film of small crystals. By filing, that film was removed, and in addition just so much more of the underlying crystal as to leave the crystal 0.110 inch thick.

The photomicrographs on Plate IX. showed the crystalline structure of the test-pieces after heat treatment.

During the mechanical testing the authors attempted to obtain figures for both limit of proportionality and elastic limit. The elastic limit was found by subjecting a specimen to progressively increasing loads, and the elastic limit was taken as the lowest stress at which permanent elongation was produced.

The elongation produced by each stress was read by extensometer and the results plotted. The limit of proportionality was taken as that stress at which the curve broke away from the straight.

Miss C. F. ELAM wrote in reply that she thanked Professor Desch for drawing attention to the apparent importance of planes of indices (112) in the deformation of iron. In reply to Dr. Johnson, she would like to point out that as both crystals were subject to attack by the etching reagent for the same period of time, if the surface of one were dissolved more rapidly or less uniformly than the other, it indicated a difference due to the orientations of the crystals, which might be described more accurately as a difference in "directional" hardness. That was clear from the fact that a particular scratch was sometimes more noticeable on one crystal, while another scratch showed more clearly on the other. She did not state that the pitted crystal was actually softer than the other, but only that the two crystals were different.

Iron and Steel Institute.

THE EFFECT OF TEMPERATURE ON THE BEHAVIOUR OF IRON AND STEEL IN THE NOTCHED-BAR IMPACT TEST.*

By R. H. GREAVES AND J. A. JONES
(RESEARCH DEPARTMENT, WOOLWICH).

1. INTRODUCTION.

MUCH work has been carried out on mechanical tests of iron and steel at low and at high temperatures, and several investigators have devoted special attention to the effect of temperature on the notched-bar impact test. A brief summary of this work is given in Table I., and the principal conclusions which have been drawn from it are referred to later. In comparing the results obtained by different investigators, it is as important to consider the different conditions of test employed as it is to know the composition and treatment of the steels tested. For this reason the conditions of testing are recorded as fully as possible. Many typical diagrams are reproduced from the original papers, or redrawn from the numerical results given therein, in a recent paper by Körber and Pomp.⁽²¹⁾

Among the objects which the authors had in view in carrying out this study of the effect of temperature on the behaviour of iron and steel in the notched-bar impact test were the determination of the influence of changes of atmospheric temperature on the test, the investigation of the embrittling action of cold, and the elucidation, if possible, of some features of the "blue-brittleness" of iron and steel, and of the "temper-brittleness" of alloy steels. These objects have entailed some work in other directions—for example, in investigating the influence of the form of the test-piece on the indications of the test, and in comparing the results of impact and slow-bending tests on notched bars.

In this work a large variety of material has been tested,† and

* Communication from the Research Department, Woolwich.

† Work on non-ferrous metals and alloys is described in *Journal of the Institute of Metals*, 1925, No. II.

TABLE I.—*Notched-Bar Impact Tests on Iron*

Reference.	Date.	Authors.	Material Investigated.
1	1906	Charpy	Mild steel; nickel and nickel-chromium steels.
2 and 3	1909	Guillet and Révillon	Carbon steels (0.2 to 1.2 per cent. carbon), nickel and nickel-chromium steels, all annealed.
4	1909	Guillet and Révillon	Annealed 0.35 per cent. carbon steel.
4 and 5	1910	Guillet and Révillon	Martensitic and austenitic alloy steels.
6	1913	Goerens and Hartel	Mild steel.
7	1916	Reinhold	Carbon steels (0.08 to 0.4 per cent. carbon).
8	1919	Monypenny	Mild steel; heat-treated nickel, nickel-chromium and chromium steels, including "stainless" steel.
9	1921	Strauss and Fry	Mild steel (carbon 0.06 to 0.08 per cent.) in various conditions, as rolled and annealed.
10	1921	Kaiser	Wrought iron and mild steel.
11	1922	Guillet and Cournot	Electrolytic iron, carbon steels (0.1 to 0.8 per cent. carbon), nickel and nickel-chromium steels, all annealed; air-hardened nickel-chromium steel; ferro-nickel alloys.
12	1922	Chevenard	Low carbon ferro-nickel alloys.
13	1922	Edert	Nickel-chromium, chromium-vanadium, and high chromium steels.
14 and 15	1923	Langenberg	Carbon, nickel, and nickel-chromium steels, annealed and heat-treated.
16	1924	Aitchison (and Staff of the Engineering Department of the National Physical Laboratory)	Heat-treated carbon and nickel-chromium steels. Cold-worked carbon steels.
17	1924	Richardson and MacNutt	Mild steel (carbon 0.18 per cent.), worked at different temperatures.
18	1924	Goerens	Mild steel.
19	1924	Mailänder	Mild steel; investigating specially the effect of change of breadth of test-piece over the range -20° to 100° C.
20	1925	Körber and Pomp	Steel castings, as cast and annealed.
21	1925	Körber and Pomp	Mild steel (carbon 0.05 per cent.), quenched and tempered, rolled, worked at blue heat, overheated, &c.
22	1925	Maurer and Mailänder	Mild steel, effect of cold-work, heat treatment, form of test-piece, and speed of deformation.

and Steel at Different Temperatures.

Range of Temperature. Deg. C.	Testing Machine Used.	Form of Test-Piece.			
		Dimensions.	Width of Gap.	Notch	
				Radius.	Depth.
— 80 to 600	200 kgm. Charpy	mm. 30 × 30 × 160	mm. 120	mm. 2	mm. 15
20 to 600	60 kgm. Guillery	10 × 10 × 60	40	1	2
20 to 600	Guillery machine at striking energy of 60, 40, and 20 kgm.	„	„	„	„
20 to 600 or 800	60 kgm. Guillery	„	„	„	„
— 80 to 900	75 kgm. Charpy	30 × 10 × 160	120	2	15
— 40 to 920	75 kgm. Charpy	„	„	„	„
20 to 1000	30 kgm. Charpy	10 × 10 × 60	40	0.25 45° V.	2
20 to 350	...	20 × 20 × 80	...	45° V.	5
— 85 to 15	75 kgm. Charpy	30 × 30 × 180	120	2	15
— 190 to 20	60 kgm. Guillery	10 × 10 × 60	40	1	2
— 190 to 20	60 kgm. Frémont	10 × 8 × 35	22	1 wide	1
20 to 700	10 kgm. Charpy type	10 × 8 × 100	70	$\frac{2}{3}$	5
— 62 to 537	300 kgm. Charpy	30 × 30 × 155	120	2	15
— 80 to 18	N.P.L. Charpy type	Several 10 × 10 × 60	forms including 40	0.25 45° V.	2
— 62 to 370	30 kgm. Charpy	10 × 10 × 55	40	$\frac{2}{3}$	5
20 to 500	...	30 × 30 × 160	120	2	15
— 70 to 400	40 and 150 kgm.	20 × (5 to 30) × 110	75	45° V.	5
20 to 500	75 kgm. Charpy	30 × 30 × 160	120	2	15
— 70 to 500	75 kgm. Charpy	15 × 15 × 160	120	1.5	7
— 70 to 600	...	Various	...	...	...

it will render the results more accessible if those of standard impact tests are first given under the heading of the respective materials, and features of more general interest discussed later.

2. METHOD OF TESTING.

The tests were made in the 30-kilogram-metre Charpy machine. The B.E.S.A. test-piece was adopted as the standard throughout. The results first given were therefore obtained under the following conditions :

Dimensions of Test-Piece.	Form of Notch.	Width of Gap.	Machine.	Striking Velocity.
10 × 10 × 60 mm.	45° V, 0.25 mm. root radius 2 mm. deep	40 mm.	30 kgm. Charpy	5.3 m. per sec.

Comparative tests with other forms of test-piece were also made. The specimens were placed in a bath or furnace at the required temperature, and were kept at the temperature for half an hour before breaking. They were then removed to the anvil of the machine and broken immediately. The time occupied in breaking, measured from the moment of removal from the constant temperature bath or furnace, was not more than five seconds, and the change of temperature which occurred in this time at the notch in the centre of the specimen was usually very small. This was especially the case when the test-piece was withdrawn from a liquid bath, and was thus protected by a film of the liquid. Temperature changes were measured by a thermocouple embedded in a hole drilled down to the plane of the notch in test-specimens withdrawn from the furnace and placed on the anvil of the machine in the usual way. The fall of temperature observed was as follows :

Time after withdrawal	.	.	5 secs.	10 secs.	15 secs.
Salt-bath at 620° C.	.	.	nil	6° C.	29° C.
Electric furnace at 800° C.	.	.	10° C.	25° C.	50° C.

The corrections applied to the temperatures of test-pieces withdrawn from the electric furnace were -10° C. at 700° to 850° , and -15° C. at 900° to 1000° C. No correction was applied to test-pieces heated in the salt-bath or other media at lower temperatures.

The required temperatures were attained as follows :

— 80° C.	Ether and excess of solid carbon dioxide.
— 80° to — 20° C.	Ether and solid carbon dioxide.
— 20° to 0° C.	Ice and salt.
0° C.	Melting ice.
Atmospheric to 100° C.	Water.
120° to 250° C.	Oil-bath.
250° „ 650° C.	Salt-bath of fused nitrates.
650° „ 1000° C.	Electric muffle furnace.

The possibility that chemical action of the fused nitrates would reduce the impact figures was considered, though such action seemed unlikely to occur (in view of Benson's results⁽²³⁾) in so short a time. The effect was carefully examined by a series of comparative tests on mild steel at 650° C. after heating for half an hour (*a*) in a salt-bath, or (*b*) in an electric muffle. The results of tests were identical. In a series of tests carried out in another connection, oil-hardened and fully tempered carbon and nickel steel gave no change in impact figure after immersion in the salt-bath of fused nitrates at 350° C. for forty-eight days.

In order not to overburden the paper with figures, the individual results are not given in full; diagrams only are given in the majority of cases. From these the actual average impact figure at any temperature can be read. The figures from which the diagrams are prepared are the averages of two, four, or more individual results. Important points on the curves were confirmed by four or more results; intermediate points were generally fixed by two tests, if closely concordant. Any points representing averages of individual results showing considerable variation from the average are specially noted.

3. MATERIALS USED.

Chemical analyses are given in Table II., and tensile tests in Table III.

Swedish Bar Iron.—Test-pieces were cut longitudinally from the plate as rolled (Fig. 1). Brinell hardness, 83.

Armco Iron.—Two samples (rectangular bar, $2\frac{1}{2}$ in. by $\frac{1}{2}$ in.) were examined, both in the condition as rolled. Test-pieces were cut transversely (Fig. 2). Brinell hardness: *Sample A*, 85; *Sample B*, 86.

Armco iron was used for determining the effect of variations

in the notch (Figs. 23 and 24) and in the rate of straining (Figs. 21 and 22).

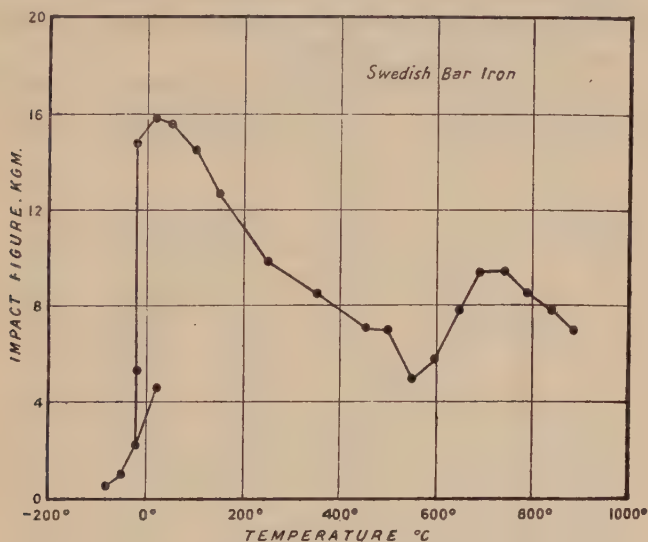


FIG. 1.—Notched-bar impact figure of Swedish bar iron at different temperatures.

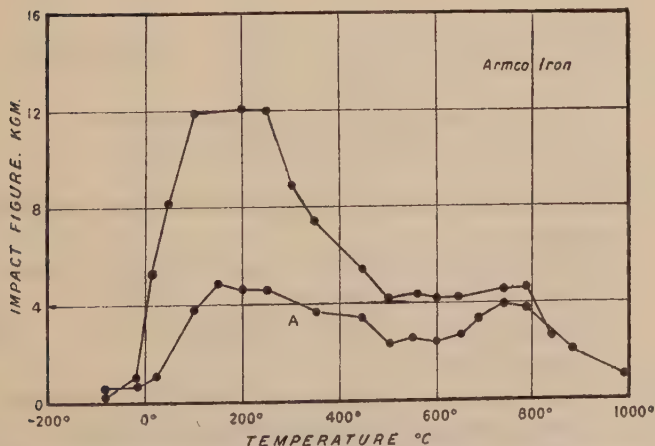


FIG. 2.—Notched-bar impact figure of Armco iron at different temperatures.

Mild Steel.—Three specimens were examined :

Sample A.— $1\frac{1}{4}$ inch round bar as rolled ; test-pieces longitudinal (Fig. 3). Brinell hardness, 128.

This steel was used for determining the effect of different rates of straining (Fig. 23).

Sample B.— $\frac{3}{4}$ -inch plate ; test-pieces transverse ; tested as

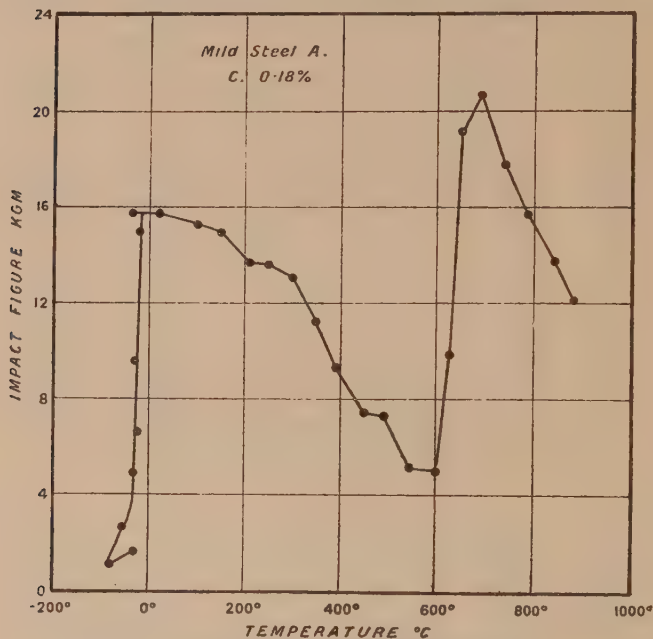


FIG. 3.—Notched-bar impact figure of mild steel at different temperatures.

rolled (Brinell hardness, 113), and also after the following treatments :

- (1) Heated at 900° C. for one hour and quenched in water. Brinell hardness, 146.
- (2) Annealed at 900° C. and slowly cooled. Brinell hardness, 108.
- (3) Overheated. Heated at 1250° C. for one hour and slowly cooled. Brinell hardness, 108.
- (4) Cementite globularised. Normalised steel reheated to 710° C. and very slowly cooled. Brinell hardness, 111.

The results are shown in Figs. 4 and 5. The sulphur and phosphorus contents of this steel were somewhat high.

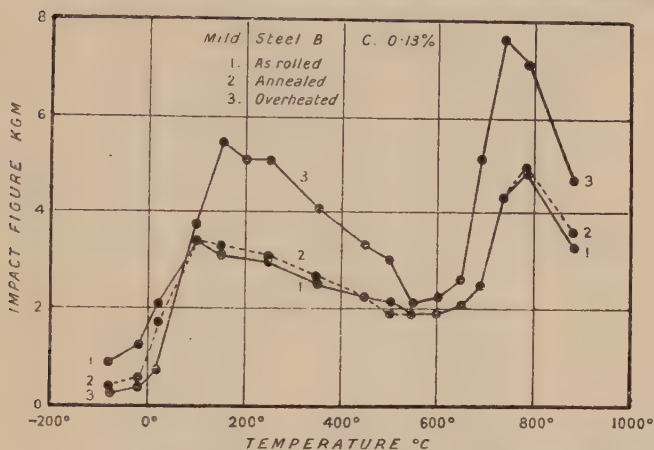


FIG. 4.—Notched-bar impact figure of mild steel at different temperatures. Effect of treatment.

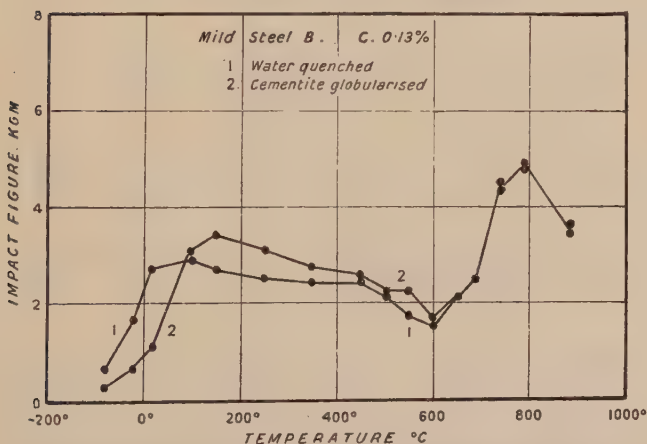


FIG. 5.—Notched-bar impact figure of mild steel at different temperatures. Effect of treatment.

Sample C.— $\frac{3}{4}$ -inch plate; test-pieces transverse; tested as rolled (Fig. 6), Brinell hardness, 112. After cold-rolling to $\frac{5}{8}$ inch, Brinell hardness, 160. After cold-rolling to $\frac{1}{2}$ inch, Brinell hardness, 184.

Carbon Steel.

Sample A.—Carbon, 0·39 per cent.; test-pieces were cut transversely from the forging after the steel had received the following treatments (Fig. 7) :

- (1) Normalised. Heated at 900° C. for one hour and cooled in air. Brinell hardness, 171.
- (2) Oil-hardened from 900° C., tempered for two hours at 650° C. and cooled in air. Brinell hardness, 194.

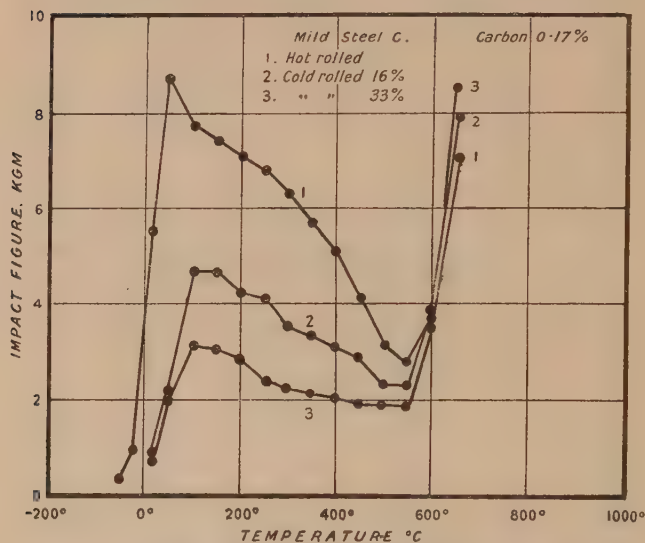


FIG. 6.—Notched-bar impact figure of mild steel at different temperatures. Effect of cold-work.

Sample B.—Carbon, 0·45 per cent.; test-pieces were cut transversely from a forged billet, after the steel had received the following treatments (Fig. 8) :

- (1) Normalised. Heated to 880° C. and cooled in air. Brinell hardness, 170.
- (2) Oil-hardened from 870° C.; tempered at 650° C. for one hour, and cooled in air. Brinell hardness, 203.

This steel was used for slow bending tests on notched bars.

Sample C.—Carbon, 0·52 per cent.; contained high sulphur and phosphorus. Test-pieces were cut transversely from

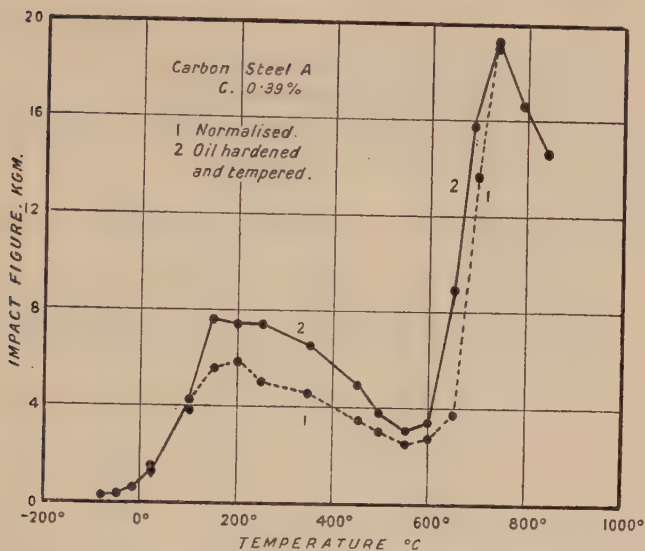


Fig. 7.—Notched-bar impact figure of 0.39 per cent. carbon steel at different temperatures.

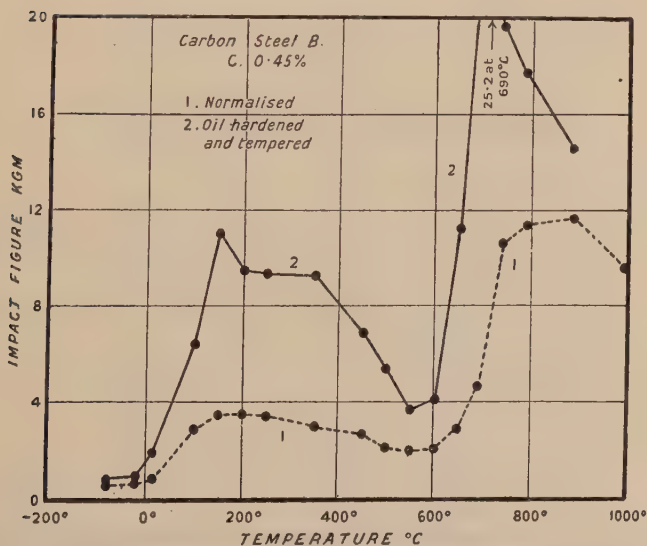


Fig. 8.—Notched-bar impact figure of 0.45 per cent. carbon steel at different temperatures.

a forged billet after the steel had received treatments identical with those given to Sample B above. Brinell hardness, 184 and 216 respectively (Fig. 9).

Nickel Steel (carbon 0.35 per cent., nickel 3.77 per cent.).—Test-pieces cut transversely (Fig. 10) from a forging after the steel had been :

(1) Annealed at 900° C. and cooled in the furnace. Brinell hardness, 190.

(2) Oil-hardened from 900° C.; tempered at 620° C. for two hours and cooled in air. Brinell hardness, 219.

This steel was used for slow bending tests on notched bars.

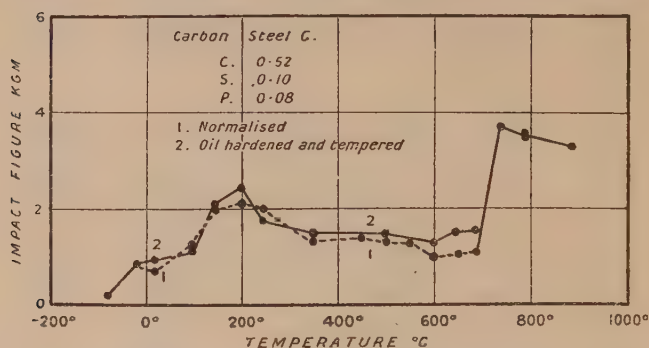


FIG. 9.—Notched-bar impact figure of high sulphur and phosphorus carbon steel at different temperatures.

Nickel-Chromium Steel.

Sample A (carbon 0.23 per cent., nickel 3.72 per cent., chromium 0.92 per cent.).—Test-pieces cut transversely (Fig. 11) from a forging after the steel had been :

(1) Annealed at 900° C., and cooled in the furnace. Brinell hardness, 261.

(2) Oil-hardened from 900° C.; tempered at 650° C. for two hours and cooled :

(a) In water. Brinell hardness, 243.

(b) Slowly at 0.3° C. per minute. Brinell hardness, 240.

This steel was used for slow bending tests on notched bars.

Sample B (carbon 0.38 per cent., nickel 1.93 per cent., chromium 0.62 per cent.).—Test-pieces were cut trans-

versely (Fig. 11) from a forging which had been oil-hardened from 880° C., tempered at 660° C. for two hours and cooled in air. Brinell hardness, 222.

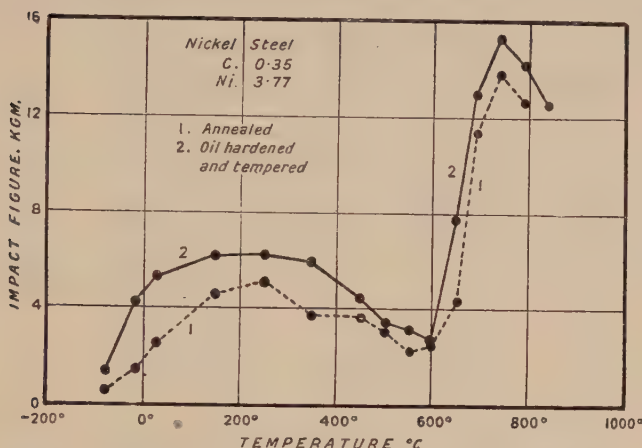


FIG. 10.—Notched-bar impact figure of nickel steel at different temperatures.

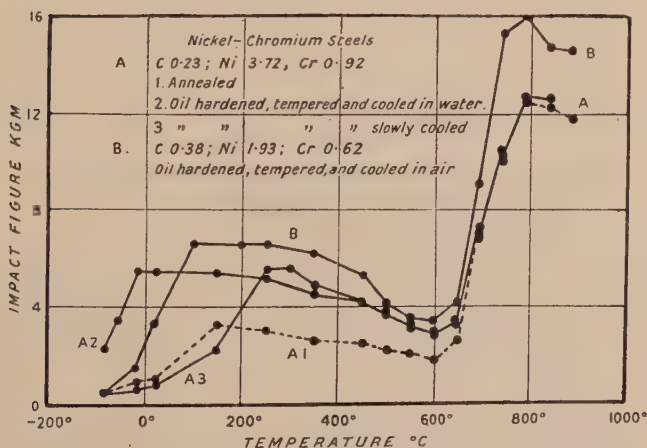


FIG. 11.—Notched-bar impact figure of nickel-chromium steels at different temperatures.

This steel was used for determining the effect of different forms of notch (Fig. 25).

Nickel-Chromium-Molybdenum Steel (carbon 0.28, nickel 2.45, chromium 0.65, molybdenum 0.43 per cent.).—Test-pieces were cut transversely (Fig. 12) from a forging which had been oil-hardened from 900° C., tempered at 670° C. for two hours, and cooled in air. Brinell hardness, 242.

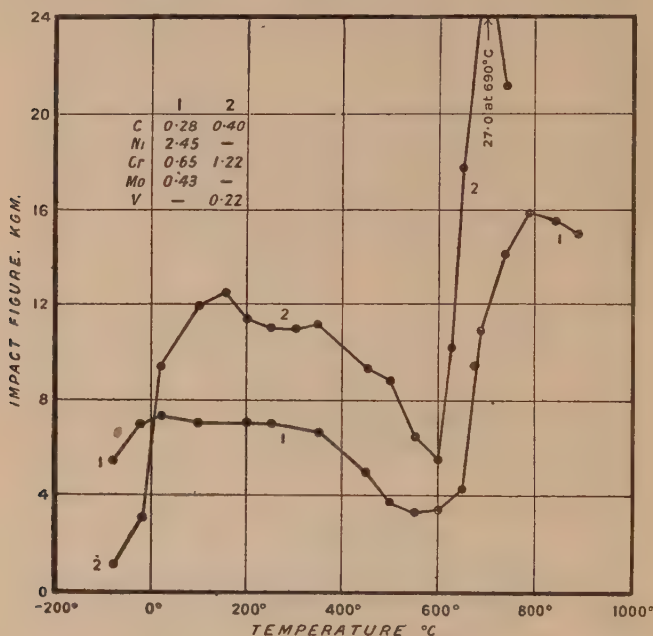


FIG. 12.—Notched-bar impact figures of oil-hardened and tempered nickel-chromium-molybdenum and chromium-vanadium steels at different temperatures.

Chromium-Vanadium Steel (carbon 0.40, chromium 1.22, vanadium 0.22 per cent.).—Test-pieces were cut longitudinally (Fig. 12) from a rolled bar after the steel had been oil-hardened from 900° C., tempered for two hours at 670° C. and cooled in water. Brinell hardness, 238.

Stainless Steel (carbon 0.43 per cent., chromium 12.37 per cent.).—Test-pieces were cut longitudinally (Fig. 13) from rolled bar which had been :

- (1) Very slowly cooled from 900° C. Brinell hardness, 180.
- (2) Oil-hardened from 920° C., tempered at 700° C. for two hours. Brinell hardness, 222.

4. GENERAL FORM OF THE IMPACT FIGURE-TEMPERATURE CURVES.

All the curves show some amount of similarity and can be divided into three principal regions—the region up to and including the first maximum, the vicinity of the minimum, and that of the second maximum. These will be discussed in some detail later, but for the present it may be noted that the temperatures of the minimum and second maximum are subject to less variation than those of the first maximum. In the tests with the standard test-piece, the temperature at which the minimum impact figure is reached varies between 500°C . for Armco iron and 650°C . for some heat-treated alloy steels.

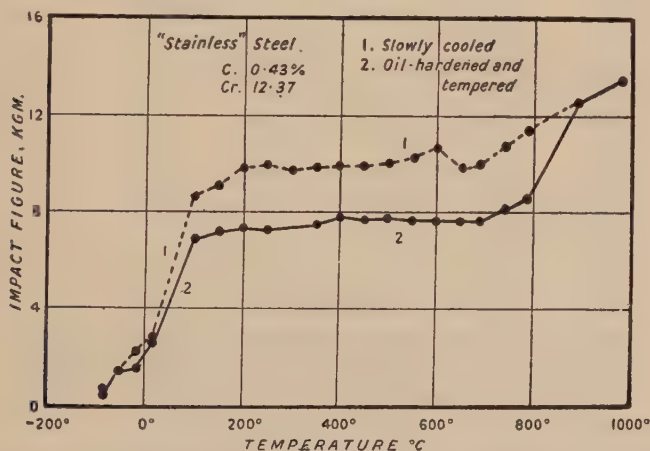


FIG. 13.—Notched-bar impact figure of stainless steel at different temperatures.

Variation of Angle of Bend with Temperature.—In a large number of tests the angle of bend of the fractured test-piece was measured. Fig. 14 represents the curve of angles of bend plotted against temperature for the chromium-vanadium steels of which the impact figures are shown in Fig. 12. The angles of bend give a sharp indication of a minimum at the same temperature as that given by energy absorbed; they give no information about maxima, as the test-pieces are all unbroken over a considerable range of temperature.

Goerens and Hartel ⁽⁶⁾ studied angles of bend very carefully and came to the conclusion that the angle of bend was at a minimum at the same temperature as the energy absorbed.

The practice of measuring the angle of bend was subsequently given up, as the information derived from the measurements did not appear to add to that given by the impact figure.

5. SLOW BENDING TESTS ON NOTCHED BARS.

The quantity directly measured in the impact test is work done in breaking or bending the test-piece. In general, the main

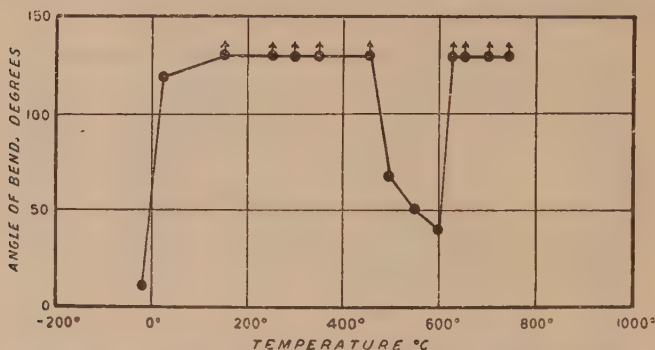


FIG. 14.—Angles of bend of notched bars of chromium-vanadium steel, tested at different temperatures. Points marked with arrows represent unbroken test-pieces. The energy absorbed by these test-pieces is shown in Fig. 12.

factor affecting the energy absorbed is the deformation undergone, and in a given type of material the effect of variation of maximum tensile strength is of secondary importance, except in so far as it is accompanied by a change in the capacity of the material to undergo deformation.

The Humfrey method of obtaining autographic diagrams of the bending of notched bars provides a valuable means of distinguishing between the factors involved, and, being carried out slowly, it provides a connecting-link in the correlation of notched-bar impact tests and static tensile, compression, and torsion tests.

The Humfrey method was therefore adapted for work at raised temperatures in the manner indicated in Fig. 28 (Plate XI.).

The test-piece, fitted into adapters of stainless steel (oil-hardened and tempered at $450^{\circ}\text{C}.$), was heated in an electrically heated muffle furnace $5\frac{1}{2}$ in. by 2 in. section, with rounded sides. The muffle was closed at one end, and through this end a hole was drilled to admit the adapter which was clamped in a vice outside the furnace. The test-piece made an easy sliding fit into a square hole slotted out of the end of the adapter, which was also provided with a hole drilled obliquely in which a thermocouple junction was placed in contact with the test-piece. To the other end of the

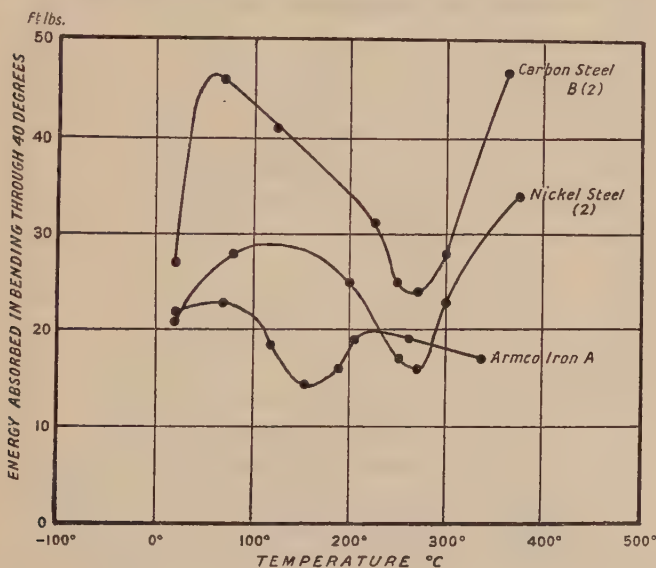


FIG. 15.—Energy absorbed in slow bending tests on notched bars.

test-piece was fitted an extension bar (of the same stainless steel) which just projected from the mouth of the muffle. The mouth of the muffle was closed with loose asbestos wool and an asbestos plug. The required temperature having been obtained and held constant for twenty to thirty minutes, the usual bending arm of the Humfrey machine was fitted to the extension piece, the asbestos door removed, leaving the loose asbestos wool to prevent air-draughts, and the test carried out in the usual way. It was found that the temperature remained very steady during the test, and could be kept fairly constant, even if, for special reasons, the test

were carried out very slowly. Some tests were made at very slow rates of bending, *e.g.* 15 degrees in sixty to eighty minutes, but, for tests at so slow a rate, water-cooling of the end of the bending arm must be adopted. The results of tests made at the ordinary rates are given in Table IV. The maximum angle of bend which could be produced with the arrangement used was 40 degrees, and many test-pieces showed an appreciable resistance to further bending at this angle. The bending moment at

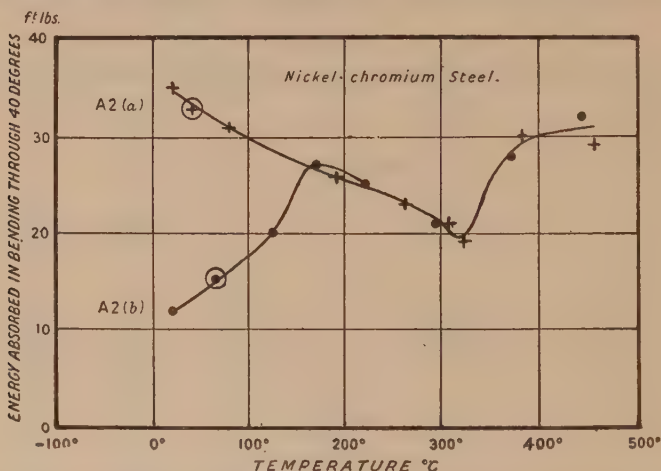


FIG. 16.—Energy absorbed in slow bending tests of notched bars of nickel-chromium steel in condition (a) as water-cooled, (b) as slowly cooled after tempering: the points surrounded by circles represent test-pieces tested after cooling from 330° C.

40 degrees is therefore recorded, it being clear that the figures given for energy absorbed fall below those for a complete break by the greatest amount when the residual bending moment is greatest.

Results of slow bending tests on notched bars are shown in Figs. 15 and 16, and some typical diagrams are reproduced in Figs. 17 and 18. The minimum absorption of energy in the slow bending of notched bars occurred at the following temperatures :

Armco iron	170° C.
Oil-hardened and tempered 0.45 per cent. carbon steel	270° C.
" " " nickel steel	270° C.
" " " nickel-chromium steel	320° C.

6. THE BEHAVIOUR OF TEMPER-BRITTLE STEEL AT RAISED TEMPERATURES.

It was pointed out by Monypenny⁽⁸⁾ that the notched-bar impact figure of temper-brittle nickel-chromium steel showed a

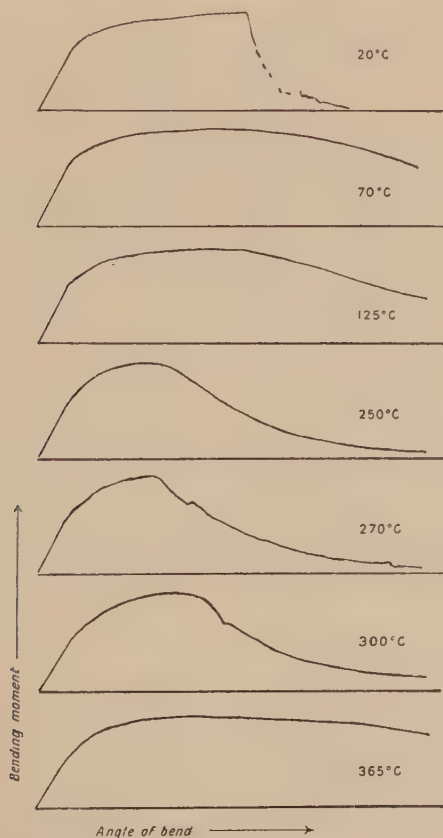


FIG. 17.— $\frac{2}{3}$ actual size. Autographic diagrams of slow bending tests on notched bars of oil-hardened and tempered carbon steel, B2, carbon 0.45 per cent. Impact tests in Fig. 8.

considerable increase at raised temperatures, and at temperatures above about 350° C. its behaviour was identical with that of the same steel in the condition giving a high notched-bar impact figure at atmospheric temperatures. This has been confirmed

(Fig. 11). Slow bending tests in the Humfrey machine also show that the two varieties of the same steel, which have been

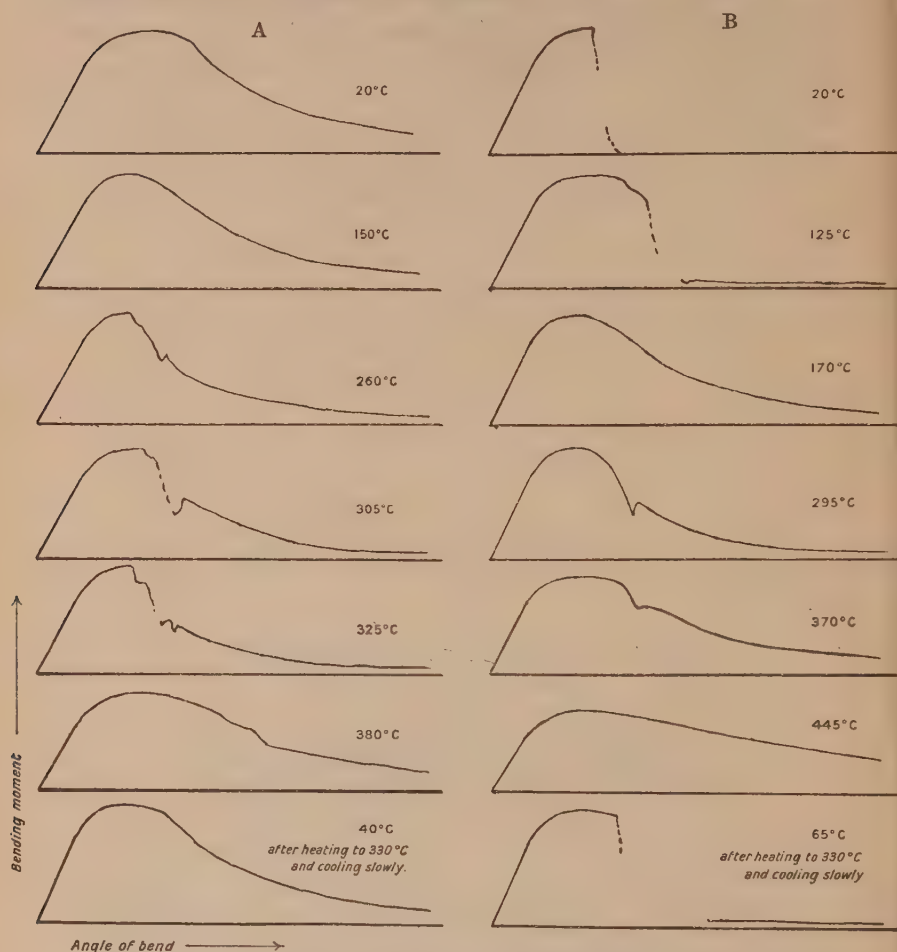


FIG. 18.— $\frac{2}{3}$ actual size. Autographic diagrams of slow bending tests on notched bars of nickel-chromium steel A, oil-hardened, tempered, and (A) cooled in water, (B) slowly cooled. Impact tests in Fig. 11.

cooled at different rates from the tempering temperature, and differ only in their notched-bar impact figures, lose this latter distinction at a temperature below 200° C., and at higher temperatures behave in an identical way in the slow bending test on

notched bars. They still, however, preserve their identity: for notched-bar test-pieces, after being heated to 330°C . and cooled slowly to 40° or 65°C ., still show their characteristic difference of behaviour in the slow bending test. Typical autographic diagrams are reproduced in Fig. 18.

7. THE EFFECT OF RATE OF STRAINING, AND COMPARISON WITH STATIC TESTS.

The importance of rate of straining in all tests carried out at high temperatures is universally recognised. It was pointed out in connection with impact tests by A. Le Chatelier,⁽²⁵⁾ and was specially considered by Guillet and Révillon.⁽⁴⁾ They broke test-pieces of an annealed carbon steel in the Guillery machine at 60, 40, and 20 kilogrammes striking energy respectively, corresponding to striking velocities of 8.8, 7.2, and 5.0 metres per second. Over this somewhat narrow range of striking velocity the results were not markedly different. The minimum occurred at about 480°C . in each series of tests: the first maximum occurred at 110° to 180°C ., the temperature being very slightly higher for the higher striking velocity. Recently Maurer and Mailänder,⁽²²⁾ using boiler-plate steel in the form of test-pieces $30 \times 16 \times 160$ millimetres, with a notch 2-millimetre radius and 15 millimetres deep, obtained the following results in a pendulum machine, gap 120 millimetres:

Striking Energy.	Striking Velocity.	Temperature of	
		First Maximum.	Minimum.
150 kgm.	5.5 m. per sec.	150°C .	510°C .
40 "	3.0 " "	about 100°C .*	460°C .
slow bending test		20°C .	200°C .

* Interpolated.

Maurer and Mailänder give representative load-deflection diagrams obtained in their slow bending tests. These diagrams and the temperature of minimum energy absorption agree with those given in the previous section. The minima occur at about the temperature at which the steels in question show maximum tensile strength and minimum elongation and reduction of area.

TABLE IV.—*Slow Bending Tests on Notched Bars.*

Material Tested.	Temperature of Test.	Energy absorbed in Bending through 40 Degrees.	Bending Moment supported by the Test-Piece after Bending through 40 Degrees.	Maximum Bending Moment.
Armco iron. Sample A	° C.	Ft.-lbs.	Ft.-lbs.	Ft.-lbs. Degs.
	20	22	15	42 at 18
	70	23	25	36 „ 20
	120	18.5	15	45 „ 15
	155	14.5	5	40 „ 16
	190	16	10	45 „ 15
	205	19	15	42 „ 16
	260	19	15	40 „ 21
	337	17	10	38 „ 24
0.45 per cent. carbon steel, oil-hardened and tempered Sample B, 2	° C.	Ft.-lbs.	Ft.-lbs.	Ft.-lbs. Degs.
	20	27	nil	85 at 21
	70	46	65	83 „ 24
	125	41	48	77 „ 23
	225	31	12	77 „ 16
	250	25	9	74 „ 12
	270	24	8	75 „ 12
	300	28	15	76 „ 16
	365	47	56	80 „ 33
Nickel-steel, oil-hardened and tempered	° C.	Ft.-lbs.	Ft.-lbs.	Ft.-lbs. Degs.
	20	21	7	75 at 14
	80	28	15	70 „ 15
	200	25	12	65 „ 14
	250	17	8	65 „ 10
	270	16	6	63 „ 10
	300	23	15	66 „ 15
	375	34	35	68 „ 20
Nickel-chromium steel, oil-hardened, tempered, and cooled in water Sample A, 2 (a)	° C.	Ft.-lbs.	Ft.-lbs.	Ft.-lbs. Degs.
	20	35	20	95 at 13
	80	31	15	88 „ 12
	150	30	15	86 „ 12
	190	26	12	85 „ 11
	260	23	10	83 „ 9
	305	21	7	83 „ 10
	325	19	7	78 „ 10
	380	30	20	75 „ 12
	455	29	25	65 „ 12
	Heated to 330 and cooled to 40	33	16	88 „ 13
The same nickel-chromium steel, oil-hardened, tempered, and slowly cooled Sample A, 2 (b)	° C.	Ft.-lbs.	Ft.-lbs.	Ft.-lbs. Degs.
	20	12	nil	95 at 11
	125	20	5	86 „ 12
	170	27	15	82 „ 11
	220	25	12	80 „ 11
	295	21	10	82 „ 10
	370	28	16	74 „ 13
	445	32	35	60 „ 14
	Heated to 330 and cooled to 65	15	5	88 „ 11

It is unnecessary here to attempt to summarise the large amount of work which has been done on the tensile testing of iron and steel at high temperatures, particularly in view of the recent publication of a valuable résumé of the subject with a bibliography, by French and Tucker.^(26, 27) It should be noted, however, that static tensile tests may be carried out in two types of machine:

1. Those exerting a sustained load, and permitting creep to continue at a constant load.
2. Those exerting a uniformly (or intermittently) increasing strain in which creep is checked by the accompanying fall of stress.

The results of such tests carried out at high temperatures are not identical. A few tests which illustrate the importance of the "time factor," or rate of straining, have been made in a specially constructed straining apparatus. This is shown in Fig. 29 (Plate XII.). The test-piece was linked up in series with a test-piece of heat-treated alloy steel of high elastic limit, serving as a weigh-bar, to which was fitted a Ewing extensometer. Strain was applied by screw gearing and could be read by means of graduations on the rotating toothed wheel. The resulting stress was measured by the elastic extension of the weigh-bar. The test-piece could be surrounded by a jacket or furnace and brought to any required constant temperature before the test. In order to attain a steady state the temperature was held constant for about half an hour before the test, which was made by applying equal increments of strain to the system at fixed intervals and measuring the elastic extension of the weigh-bar. In this way tests were made ranging in duration from a few minutes to several hours. Typical load diagrams plotted from the results are shown in Fig. 19. These diagrams may be summarised thus:

Stress induced in the Material strained beyond its Elastic Limit by a given Extension.	Temperature of Test.	
	Armco Iron.	Heat-Treated Nickel-Chromium Steel.
	Deg. C.	Deg. C.
Greater when quickly than when slowly strained	— 80	20
Same whether quickly or slowly strained	0	100
Greater when slowly than when quickly strained	100	200

In general, with very slow deformation a given strain gives rise to a smaller stress than with rapid deformation, unless the conditions are such as to allow appreciable strain-hardening to occur with each increment of strain, in which case the stress induced is greater.

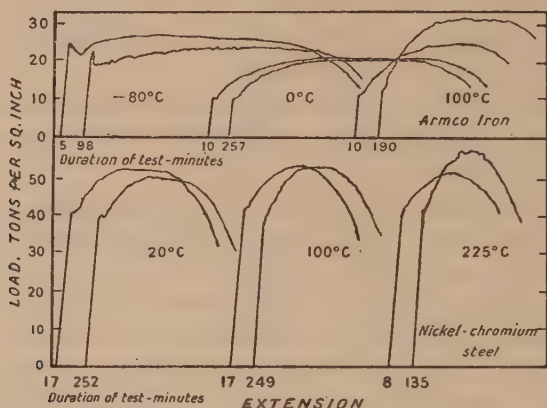


Fig. 19.—Load extension diagrams of Armco iron (sample A) and of a nickel-chromium steel (similar to sample A2).

The stress induced by a given strain will be at a maximum at the temperature at which restoration of elasticity proceeds at such a rate as to provide continuously the necessary increased resistance to further straining. As the temperature rises the rate becomes more rapid and softening sets in after a shorter interval. With softening comes the possibility of creep if the rate of straining is sufficiently slow to permit it. Hence steel will show its maximum tensile strength at a lower temperature when slowly strained than when rapidly strained.

Armco iron, in slow tests carried out in the straining apparatus described above, shows a maximum tensile strength at about 180° C.; in tests carried out in ten minutes the maximum is raised to 350° C. (Fig. 20). To effect this rise in tests under sustained load would require more rapid straining. Lea ⁽²⁸⁾ has carried out a complete series of tests on Armco iron at normal rates of loading, obtaining a maximum at 220° C. In mild steel the maximum occurred at 200° C. or 400° C. according to the speed of testing

(Fig. 21). With much more rapid straining, as in impact tests, the maxima should occur at still higher temperatures. Körber

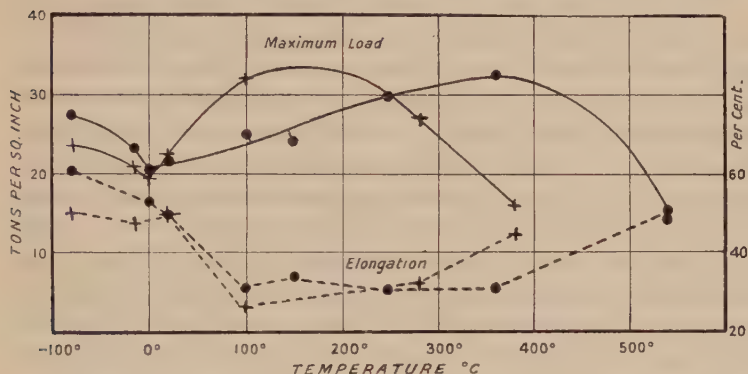


FIG. 20.—Tensile tests on Armco iron A, carried out at different rates and at different temperatures in special straining apparatus. Duration of test, • 10 minutes or less; + usually over two hours.

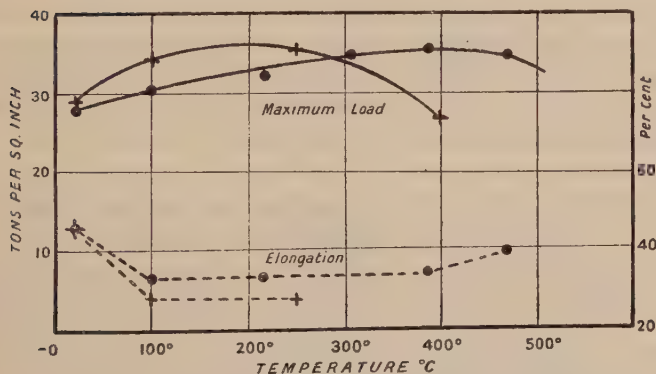


FIG. 21.—Tensile tests on mild steel carried out at different rates and at different temperatures in special straining apparatus. Duration of test, • 10 minutes or less; + usually over two hours.

and Simonsen⁽²⁹⁾ have found that in impact tensile tests mild steel shows a minimum energy absorption at 400° C. to 500° C., and 1.0 per cent. carbon steel at 500° C.

8. THE FORM OF THE IMPACT FIGURE-TEMPERATURE CURVE IN RELATION TO BLUE-BRITTLENESS.

The early literature of "blue-brittleness" is fairly extensive,⁽³⁰⁾ but the key to the interpretation of the phenomenon was given by Fettweiss⁽³¹⁾ when he pointed out the significance of the restoration of elasticity after overstrain in this connection and the importance of the time factor in the determination of the temperature at which a steel shows the maximum tensile strength and minimum ductility. A similar explanation was independently suggested by Archer.⁽³²⁾ Maurer and Mailänder⁽²²⁾ draw a useful distinction between two aspects of blue-brittleness, viz., brittleness at raised temperatures and brittleness at atmospheric temperatures due either to deformation at raised temperatures or to deformation at atmospheric temperatures, followed by ageing or low-temperature heat-treatment. As regards brittleness at raised temperatures, statements are sometimes made to the effect that the low ductility of steels in the blue-heat range is not accompanied by brittleness, as the energy absorbed in the notched-bar impact test does not show low values in this range of temperature. Such statements ignore the importance of the time factor in deformation. The "blue heat" properties of iron and steel, as noted in the previous section, are not limited to a fixed range of temperature, but occur over a range the position of which depends on the speed and mode of deformation.

9. THE EFFECT OF COLD-WORK ON THE FORM OF THE IMPACT FIGURE-TEMPERATURE CURVE.

The impact figure of iron and steel at atmospheric temperature is reduced by cold-work and still further reduced by a low-temperature heat-treatment following cold-work.^(33, 34) The most pronounced effect is found in dead-mild steel. A much greater fall in impact figure at atmospheric temperature is observed if the steel undergoes deformation at a raised temperature, the maximum effect being produced in mild steel by deformation at 250° C. to 300° C. (*i.e.* at a "blue heat").⁽³³⁾ After cold-working, or cold-working followed by ageing or low-temperature heat-treatment, or after working at a blue heat, the impact figure temperature curve up to 400° C. retains the same general character as that

of the unworked steel, but with the following differences: the maximum impact figure reached as the temperature of testing is raised is less in the worked than in the unworked steel, and the rise of impact figure to this maximum occurs at a higher temperature.^(17, 22) Increasing amounts of cold-work accentuate both these differences.

The effect of cold-work on the impact figure of a mild steel at different temperatures is shown in Fig. 6. The displacement of the steeply sloping portion of the curve towards a higher temperature, and the fall in the maximum figure attained are clearly shown, but another feature of importance is the fact that the worked steel falls to its minimum impact figure at a lower temperature the more severely it is cold-worked. This is not shown by Maurer and Mailänder's⁽²²⁾ mild steel, rolled 16 per cent. at 20° C. and heated for three hours at 250° C., which gave almost identical tests above 300° C. with a minimum impact figure at 550° C. in the worked and unworked conditions (their figure 12); but more nearly resembles the behaviour of the boiler-plate steel over-strained by different amounts in tension (their figure 10), on which tests were, however, only made at temperatures up to 400° C. Indications of similar behaviour in steel worked at a blue heat have also been observed by Körber and Pomp⁽²¹⁾ and by Richardson and MacNutt,⁽¹⁷⁾ but were limited by the range of testing temperatures employed.

In Fig. 6 it will be seen that while the normalised mild steel reached a minimum impact figure at 550° C., the same steel when reduced 16 per cent. and 33 per cent. in thickness by cold-work, reached progressively lower minima at 500° and 450° C. respectively. This is entirely in accordance with the suggestion that the minimum, common to all steels, is due to strain-hardening of the steel proceeding as rapidly as deformation occurs. Steel which is considerably strain-hardened throughout reaches the condition in which maximum strain-hardening precedes fracture at a lower temperature than a normalised steel. The impact figure then remains unaffected until the rise (due to recrystallisation occurring as deformation proceeds) sets in, when the most severely cold-worked steel shows the steepest rise to a maximum, though the initial condition of the steel makes little difference at temperatures above 600° C.

10. EFFECT OF THE FORM OF THE TEST-PIECE.

The effect of the form of test-piece is revealed in comparing results obtained by different investigators (Table V.). In each instance the lower temperature applies to iron and mild steel, and the higher temperature to high carbon and alloy steels, except that Edert's figures were obtained with nickel-chromium steels. In these results the effect of the form of the notch appears to predominate over that of other variables.

TABLE V.—*Effect of Form of Test-Piece on the Temperature at which the Impact Figure is a Minimum.*

Ref.	Authors.	Striking Energy. Kgm.	Dimensions. Mm.	Gap. Mm.	Form of Notch.	Temperature of Minimum. Deg. C.
1	Charpy .	200	30 × 30	120	2 mm. radius, 15 mm. deep	450-500
7	Reinhold .	75	30 × 10	120	„ „ „ „	425-520
6	Goerens and Hartel .	75	30 × 10	120	„ „ „ „	440-480
2, 3	Guillet and Révillon .	60	10 × 10	40	1 mm. „ 2 mm.	460-530
13	Edert .	10	10 × 8	70	$\frac{3}{8}$ mm. „ 5 „	500-600
8	Monypenny .	30	10 × 10	40	45° V., 0.25 mm. radius, 2 mm. deep	550-650
...	Present authors	30	10 × 10	40	45° V., 0.25 mm. radius, 2 mm. deep	500-650

In addition to the results obtained with the B.E.S.A. test-piece comparative tests were made on both samples of Armco iron and on nickel-chromium steel (sample B) with test-pieces of other forms, viz. :

The small Charpy test-piece .	10 × 10 mm., notch $\frac{3}{8}$ mm. radius, 5 mm. deep.
The Mesnager test-piece .	10 × 10 „ „ 1 „ „ 2 „ „
Test-pieces with "notches" {	10 × 10 „ „ 4 „ „ 2 „ „
of great radius ¹ {	10 × 10 „ „ 10 „ „ 2 „ „
Unnotched bars ¹ .	10 × 10 „ „ 200 „ „ 2 „ „

¹ Armco iron only.

The results are given in Figs. 23 to 25. It will be seen that for a wide variation in the notch the curve retains the same general form ; but that the change of radius from 10 to 200 millimetres, and, finally, to the form of the unnotched bar, gives rise to effects

of a different order. The approximate positions of the maxima and minima of the curves are shown in the following table, which refers to Armco iron, Sample A, Fig. 23 :

Radius of Notch.	$\frac{1}{2}$ Mm., $\frac{3}{4}$ Mm., 1 Mm.	4 and 10 Mm.	200 Mm.	Unnotched.
Temperature of first maximum .	200° C.	150° C.	-20° C.	-80° C.
„ „ minimum .	500°	500°	{ 500° 220° }	200°
„ „ second maximum	750°	700°	650°	520°

The results given by the 10 mm. \times 10 mm. test-piece with the “200-millimetre notch,” the form of which is shown in Fig. 22, are

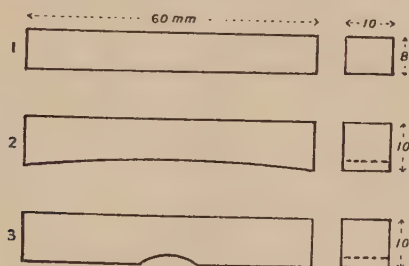


FIG. 22.—Forms of test-piece : (1) Unnotched ; (2) radius, 200 mm. ; (3) radius, 10 mm.

of interest in that they give higher results than 10 mm. \times 8 mm. unnotched bars over a considerable range of temperature, and that they effect a compromise between the behaviour of notched and unnotched bars by showing the minimum characteristic of each.

This further emphasises the fact that the essential thing about a notched-bar test is the form of the notch.

Recent work shows that important differences in the form of the impact figure temperature curve at atmospheric and slightly raised temperatures, due to displacement of the temperature of the first maximum, may also be introduced by changes in the width of the test-piece, other dimensions remaining unchanged. Thus using test-pieces 20 millimetres deep with a sharp notch 5 millimetres deep, and varying the breadth of the test-piece, Mailänder⁽¹⁹⁾ obtained an increase in impact figure as the temperature was

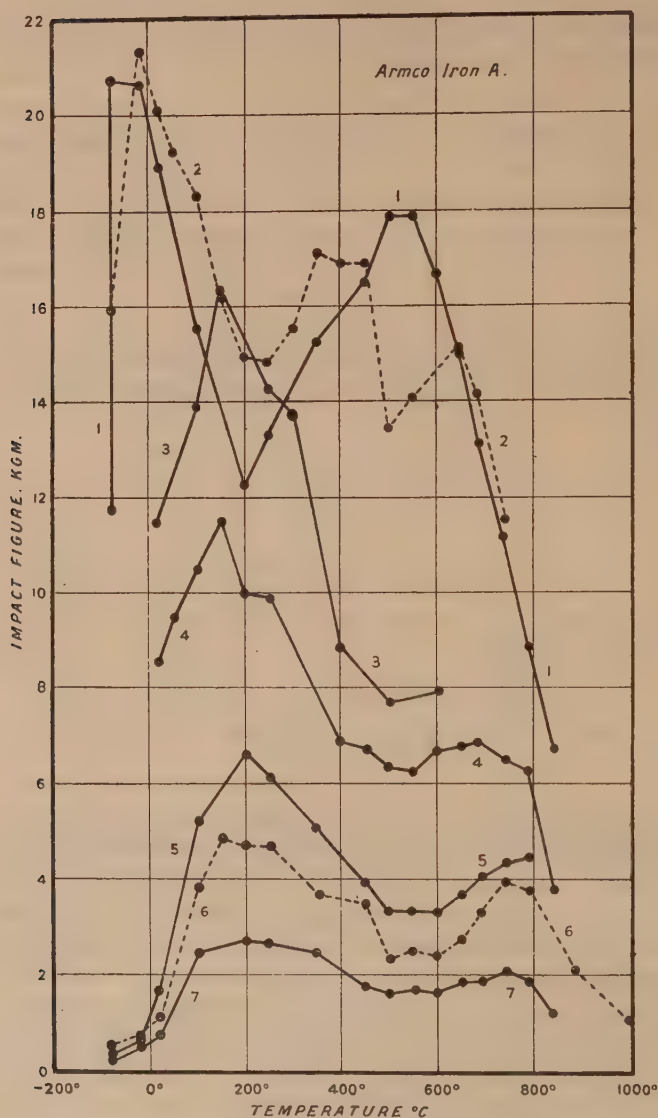


FIG. 23.—Impact figures of Armco iron tested at different temperatures. Effect of form of test-piece: (1) Unnotched; (2) radius, 200 mm.; (3) radius, 10 mm.; (4) radius, 4 mm. (5) Mesnager; (6) B.E.S.A.; (7) small Charpy.

raised from 0°C . to 20°C . when the breadth was 10 millimetres or more, and a decrease when it was 7.5 millimetres or less.

It seems probable, however, that a further study of these dimensional effects interpreted by the aid of Moser's analysis⁽³⁵⁾ of the impact figure into an "energy constant" and "rate of energy absorption" may throw considerable light on the significance of the notched-bar test.

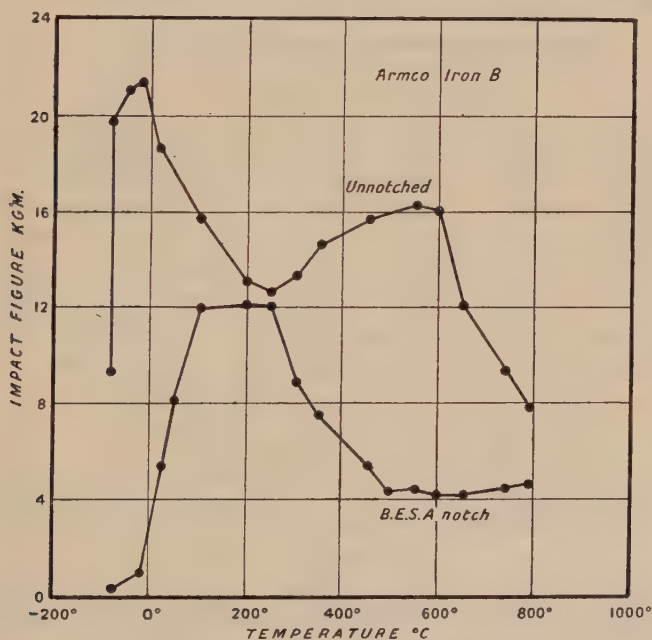


FIG. 24.—Impact figure of Armco iron, tested at different temperatures. Effect of notch.

Meanwhile, it must be recognised that changes in the form of the test-piece may displace the curves with reference to the axis of temperature, raising or lowering the temperatures of maxima and minima, and thereby modifying the indications of the test at any given temperature. This effect is to be expected, on the lines indicated in a previous section, as a natural result of the different rates of increase of stress characteristic of test-pieces of different forms.

For practical purposes the test remains an empirical test,

designed to measure the capacity of a material for plastic deformation without rupture under the most severe conditions of localisation of stress.

11. ANOMALOUS BEHAVIOUR OF WROUGHT IRON AND MILD STEEL AT ATMOSPHERIC AND LOWER TEMPERATURES.

Notched bars of Swedish bar iron and the mild steel, sample A, showed characteristics in the region of atmospheric temperature

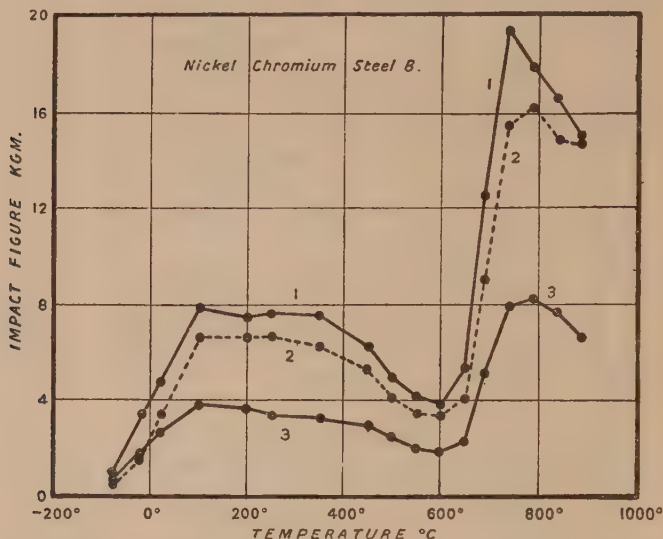


FIG. 25.—Notched-bar impact figures of nickel-chromium steel tested at different temperatures. Effect of form of test-piece: (1) Mesnager; (2) B.E.S.A.; (3) small Charpy.

which were not shared by other materials, but which were also shown by unnotched bars of Armco iron at -80°C .

At 24°C . the impact figure given by longitudinal test-pieces of the wrought iron was either about 4.5 kgm. or between 15 and 17.5 kgm. (Fig. 1); at -20°C . it was either about 2 kgm. or 15 kgm., with some intermediate variable results ranging from 4.5 to 7 kgm. The appearance of the fracture was different, test-pieces giving the smaller figure showed a partially granular fracture, those giving the higher figure were entirely fibrous. Transverse tests at 18°C . gave consistent results, averaging

2.3 kgm. Unnotched specimens of Armco iron (Figs. 23 and 24) gave alternative values for energy absorbed at -80°C. , viz.:

Sample A, 11.7 or 20 kgm.

Sample B, 9.3 or 19 „

With the mild steel (Fig. 3) the results were as follows:

24°C.	Consistent, average 15.8 kgm.
-20°	About 6.6 or 15.0 kgm.
-26°	„ 4.8 „ 9.6 „
-32°	„ 1.6 „ 15.8 „
-48°	Consistent, average 2.6 kgm.
-80°	„ „ 1.1 „

These test-pieces were all taken longitudinally side by side in pairs from $1\frac{1}{4}$ -inch round bar, the notches being cut on the face which was originally a diameter of the bar. Tests made after notching on different faces of the test-piece produced a variation of 40 per cent. in the impact figure recorded at atmospheric temperature, but these variations were of a different order from those exhibited by similar test-pieces at lower temperatures.

A similar effect was noted by Kaiser⁽¹⁰⁾ in the course of his tests on wrought iron and mild steel. He obtained the following results:

Temperature.	Individual Results. Kgm. per Sq. Mm.		Average.	
	Wrought Iron.	Mild Steel.	Wrought Iron.	Mild Steel.
15°C.	22, 16, or 10	about 18 or 13.7	16.3	14.8
-20°	about 14 or 4	consistent	9.3	1.7
-80°	consistent	„	1.4	1.3

Kaiser could not satisfactorily explain this difference. He pointed out that the test-pieces which gave 14 kgm. at -20°C. contained a little more copper than those which gave 4 kgm.; otherwise they were almost identical in composition. The fractures of the test-pieces which gave the higher results were much more fibrous than those which gave the low results, which were finely granular.

One of Langenberg's steels⁽¹⁴⁾—a heat-treated mild steel—gave, in the range 32° to -80°F. (0° to -62°C.), either a relatively high or low absorption of energy, resulting in alternative

curves for the impact figure-temperature relation over this range of temperature.

The same peculiar behaviour in mild steel is recorded by Aitchison ⁽¹⁶⁾ in the course of a paper describing notched-bar tests at low temperatures carried out in collaboration with the staff of the Engineering Department of the National Physical Laboratory.* ⁽³⁷⁾ One mild steel at 15° C. absorbed either 87·7 or 22·6 ft.-lbs. ; at -40° C. the impact figure was consistently low. Variations in the orientation of the notch in a round bar gave differences in impact figure, but it is doubtful if this can account for the somewhat definite alternative values found.

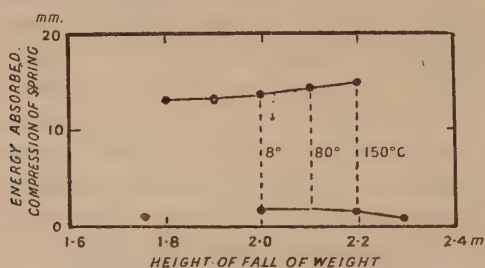


FIG. 26.—Results of impact tensile tests on wire carried out by M. Considère.

It is of interest to recall in this connection that Considère,⁽³⁶⁾ in the course of impact tensile tests on wire in a drop-weight machine, found that the energy absorbed in fracture and in the elongation underwent a sudden diminution when the height of fall was increased slightly, and that this sudden change occurred for different heights of fall at different temperatures (Fig. 26). Thus when tested with a constant striking energy and striking velocity, there was, on cooling the specimens, a temperature at which the wire showed a remarkable decrease in energy absorbed accompanied by very localised deformation. It seems most likely that definite alternative modes of deformation leading to fracture can occur in the notched-bar test over a small temperature range. In one case the deformation is very localised, in the other a considerable volume of material is affected before fracture occurs. Microscopical examination has not, however, so far given any indication of the causes of the different behaviour.

* Also by Hadfield and Main in tests at atmospheric temperature carried out in collaboration with Dr. Stanton of the National Physical Laboratory.

12. SUMMARY AND CONCLUSIONS.

The Notched-Bar Impact Figure-Temperature Curve from Low Temperatures to beyond the First Maximum.

The general character of the curve of notched-bar impact figures plotted against temperature of testing, over a range of about 500°C. from -100° to 400°C. , may be considered as falling into three classes of the types shown in Fig. 27. Omitting the exceptional case of temper-brittle nickel-chromium steel, the first maximum occurs at different temperatures between -20° and

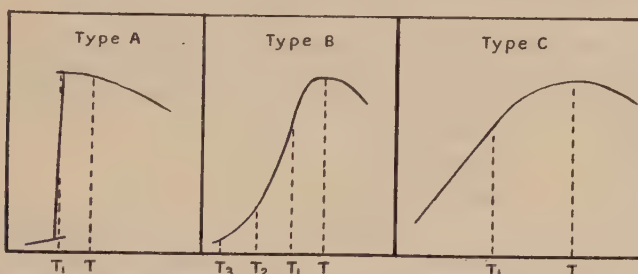


FIG. 27.—General types of impact figure-temperature curves from low temperatures to beyond the first maximum.

250°C. for different materials, but it is affected also by the form of test-piece and of the notch (§ 10). It is impossible, without allowing for many exceptions to make a general statement as to the position of the maximum, but with tests on the standard B.E.S.A. test-piece it tends to occur at the higher temperatures (200° to 250°C.) for alloy steels and heat-treated carbon steels, while for untreated carbon steels it is more frequently about 100° to 150°C. , and for wrought iron and some mild steels it is often at lower temperatures. The rise of impact figure towards the maximum is displaced by cold-work to a higher temperature, and the temperature at which the maximum occurs is generally slightly higher in cold-worked than in unworked steel (§ 9).

Effect of Variation of Atmospheric Temperature on the Results of the Test.—The general character of the effect can be followed from the diagrams, Fig. 27. If T represent the mean atmospheric temperature there is little variation in impact figure due to change in room temperature. If, however, the mean atmospheric temperature is at T_1 , there is a marked temperature coeffi-

cient, and when the curve is of type A, the results are liable to be variable (§ 11). The effect of variations in atmospheric temperature on the impact figure of the steels examined is shown in Table VI. The figures are expressed as percentage variations

TABLE VI.—*Behaviour of Iron and Steel in Notched-Bar Impact Tests at Atmospheric Temperature and Below.*

Type of Curve (Fig. 27).	Atmospheric Temperature (Fig. 27).	Percentage Fall of Impact Figure for a Fall of Temperature of 10° C.	Effect of Cold on Impact Figure.	Material.
A	T	...	Nil at first then considerable.	Tough low-carbon nickel-chromium steel.
„	T ₁	Impact figure variable over small range of temperature.	Great.	Wrought iron; mild steel.
B	T	...	Great.	None in this investigation.*
„	T ₁	10 to 20 per cent.	„	Armco iron, mild steel, annealed and heat-treated carbon steels, some annealed alloy steels, also heat-treated high-carbon, high-chromium steels (NiCr, CrV, stainless, &c.)
„	T ₂	5 to 10 per cent.	Slight on account of low figure at atmospheric temperature.	Nickel-chromium steel in the temper-brittle condition. High-phosphorus high-carbon carbon steels. Cold-worked mild steel.
C	T	...	Nil at first then steady fall.	Low-carbon nickel and nickel-chromium steels, nickel-chromium-molybdenum steel.
„	T ₁	About 5 per cent.	Steady fall.	Medium-carbon nickel and nickel-chromium steels.

in impact figure for a change of temperature of 10° C., variations below 3 per cent. being regarded as negligible.

The Effect of Cold.—The effect of low temperatures on the impact figure may be classified by reference to the same diagrams and is also indicated in Table VI.

* A mild steel examined by Charpy ⁽¹⁾ gave a curve of this type.

Thus, judged by their behaviour at low temperatures, the most satisfactory steels were alloy steels of low carbon content, and of those examined, low-carbon nickel-chromium-molybdenum and nickel-chromium steels retained their notched-bar impact figure best at low temperatures.

The Curve in the Vicinity of the Minimum.

All specimens of iron and steel examined (except stainless steel) show a curve which falls from the first maximum, and passes through a minimum at 500° to 650° C., and then attains a second maximum at above 650° C. The general character of the curve is the same for all the materials examined, but the position of the minimum is dependent on the type of iron or steel tested and more especially on the condition of the test, the form of the notch being the most important variation which enters into ordinary impact tests. The temperatures at which the minimum occurs under different conditions of testing are given in section 10.

Evidence is also given in a previous section connecting the minimum with the phenomenon of blue-brittleness, which is revealed by slow bending tests at a much lower temperature (§ 5). Since blue-brittleness is essentially a phenomenon of overstrain followed by restoration of elasticity proceeding at a rate comparable with the rate of increase of strain, the temperature at which the maximum embrittling effect appears is higher the more rapid the deformation. The rise in the embrittling temperature is thus due to speed of straining, and the rise will be greater the greater the rate of deformation (§§ 7, 8). In a notched-bar test the rate of rise of stress in the test-piece and the rate of deformation of the material is more rapid the sharper the notch. Actually, the minimum is found to occur at the highest temperature when the V-notch is employed and at a higher temperature for alloy steels than for mild steel and iron.

The Curve in the Vicinity of the Second Maximum.

The position of the second maximum, occurring between 650° and 800° C., also depends to some extent on the conditions of testing, being lower the greater the radius of the notch. It is not very clearly related to the composition of the material. The rise

of impact figure, after the minimum, is due to recrystallisation and grain growth occurring as deformation proceeds. This is a familiar feature of tensile tests at raised temperatures and is accompanied by a rapid fall in tensile strength and increase in elongation. In the tensile test on carbon and alloy steels this condition usually sets in at about 500°C . In the impact test, on account of the greater rate of deformation of the specimen, the increase in impact figure occurs at a higher temperature. The impact figure attained by iron at the second maximum is much less than at the first maximum on account of the low strength of pure iron at high temperatures; but medium carbon steels and particularly alloy steels show extremely high impact figures in this range. At still higher temperatures, at which the tensile strength of any steel, however rapidly deformed, falls to a very low value, the impact figure is again reduced.

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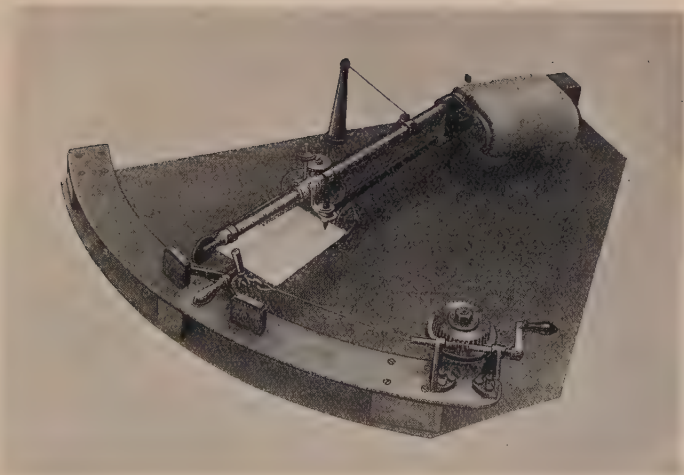
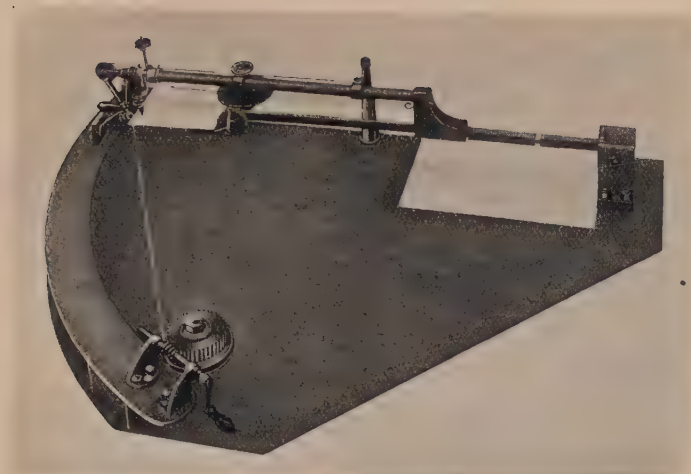
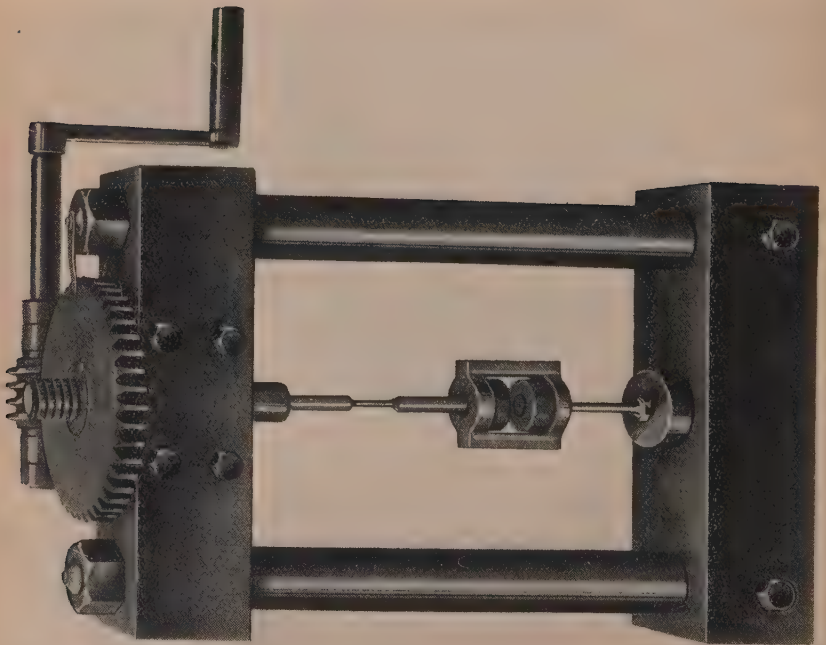
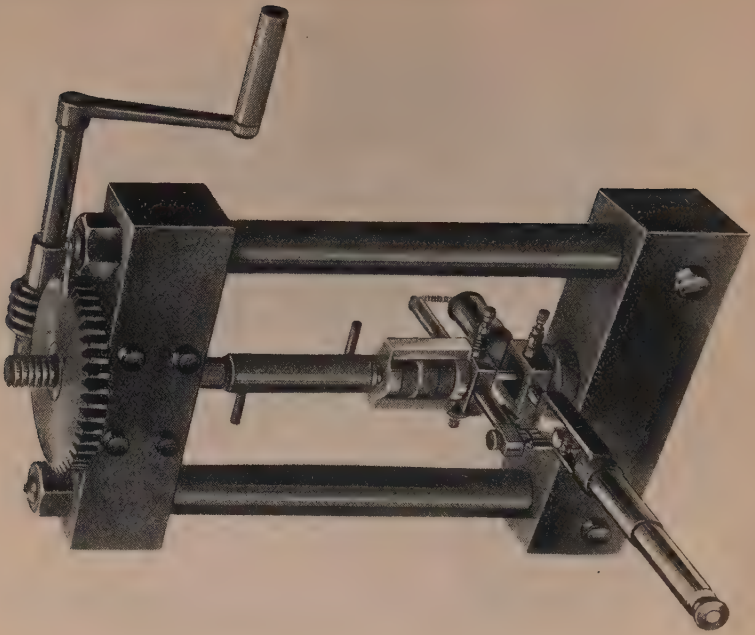


FIG. 28.—Humfrey autographic notched bar testing machine adapted for tests at high temperatures.



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- (25) A. Le CHATELIER: "Influence du temps et de la température sur les essais au choc." *Revue de Métallurgie*, 1909, vol. vi. p. 915.
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DISCUSSION.

Sir ROBERT HADFIELD, Bart. (Past-President), in opening the discussion, said he was a little surprised not to see any reference in the paper to the important work on the notched-bar impact test done by M. Frémont, to whom the Institute presented the Bessemer Gold Medal in 1921. With regard to Table II., he thought it would be somewhat more easy for reference if the compositions of each of the materials could be included in the first column. The authors referred to nickel-chromium steel, to nickel steel, to 0.45 per cent. carbon steel, and other steel, but their compositions were not given. He had no doubt the analyses appeared elsewhere in the paper, but they were not in the table, where they could be easily referred to. With regard to the effect of low temperatures, he (Sir Robert Hadfield) had dealt with a large number of experiments on the effect of very low temperatures in the paper he had read to the Institute in 1905. Some of the temperatures were as low as -180°C . The results then obtained showed that nearly all steels were embrittled at low temperatures. The only steels which showed a marked exception were those which, he thought, would be found on metallographic examination to be austenitic in their structure. It was rather curious to find that they were improved by low temperature, better results being obtained at low than at ordinary temperatures.

Mr. C. E. STROMEYER (Manchester) thought the term "blue heat" which had been used by the authors was rather too vague an expression, because temperatures were not actually measured. The term "blue heat" was, he believed, coined by Sir Nathaniel Barnaby, of the Admiralty, about forty years or more ago, and he (Mr. Stromeier) adopted it, but the critical temperature seemed rather to be one corresponding to a straw colour. It struck him that the brittleness might occur only within a very limited range of temperature, and it might be necessary to search for it with greater care than had yet been done. In a paper which he read before the Institute in 1907 and 1908 on the ageing of steel some very curious results were recorded. He found that the bad steels, those which had failed in practice, broke quite easily with one blow of the hammer after having been bent at a blue heat, whereas the good steels similarly treated bent three or four times through angles of 45° . This extraordinary difference in the behaviour of various qualities of steel suggested that blue-heat brittleness might easily elude detection. It seemed to him that it was the phosphorus and the nitrogen which assisted in producing the blue-heat brittleness, and that the better-class steels which did not contain such high percentages of those elements were not so liable to that defect.

Mr. S. A. MAIN (Sheffield) said that the anomalous behaviour of certain materials, such as wrought iron and mild steel referred to by the authors, was a feature which anyone who had had experience of applying the shock-test in a routine way must have experienced. In the paper "On Shock Tests and their Standardisation" which Sir Robert Hadfield and he gave before the Institution of Civil Engineers a few years ago, an excellent example of that particular feature was given. A specimen of mild boiler plate steel, which was tested in collaboration with Dr. Stanton of the National Physical Laboratory, in the course of ten tests broke in nine cases with a fibrous fracture, and an expenditure of energy of 20 kilogramme-metres and a bending angle of about 100° . The tenth specimen, which was cut from the same plate and quite close to the other specimens, broke with an expenditure of 10 kilogramme-metres and a bending angle of only 48° , and with quite a different, that is, crystalline, type of fracture. That only reflected what was the experience in everyday testing of certain kinds of mild steel. It was rather troublesome, because when this behaviour occurred in taking control tests it was possible to get some of the material giving comparatively low shock value and the rest a figure about twice as high, even where it was obvious from all the circumstances that there could be only slight variation in the true quality of the material. That was a difficulty which must be dealt with in connection with the practical use of shock-testing. One way, as shown in the paper mentioned, seemed to be to make the nick as sharp as possible; there was then a tendency for the crystalline or transverse fracture to be more regularly produced, so that a truer idea was obtained of the variations in the material. As the authors had explained, in the case of the transverse fracture, the fracture was quite crystalline, while in the other test it was of a shear type, or what Sir Robert Hadfield and he called the horning type. The fracture in those two cases seemed to start in a different way; in the transverse fractures it actually commenced in the transverse direction; in the other case it commenced in a longitudinal direction. He was afraid he was not able to say what were the conditions which produced that critical behaviour. That experience, however, was not confined entirely to mild steels. Something of the same kind was met with in the higher tensile alloy steels, but in that case with improving toughness there was, instead of an abrupt change, a more gradual transition from the transverse type of fracture to the horning or longitudinal shearing type. But even in those cases the tougher specimens showed what appeared to be a very much better quality than they really possessed, in relation to those of lesser toughness. He was very glad to notice that the authors had, for the bulk of their experiments, adopted the British Engineering Standards Association pattern of test-piece. The whole subject of shock-testing was a difficult one, especially in comparing the results obtained by the authors of different papers, because of the different forms of test-pieces employed; as the authors of the

present paper showed, the results obtained were very much dependent on the kind of notch used. Therefore in the present stage of the development of shock testing it was desirable in the ordinary way to keep to one pattern of test-piece; this being so, investigators could not do better than use the type which, after careful consideration, the British Engineering Standards Association had adopted.

MESSRS. GREAVES and JONES replied that they had confined their references in Table I. to papers dealing with notched-bar tests carried out over a range of temperature. They had, however, added a reference to the paper on "Shock Tests and their Standardisation," in which, as Mr. Main had pointed out, mention had been made of the anomalous behaviour of certain steels in notched-bar tests at atmospheric temperature.

The interesting observations of Mr. Stromeyer on the occurrence of the brittle range at a temperature corresponding to a straw colour agreed with their results for the slow rates of testing. The so-called "blue-heat" properties of iron and steel were not limited to a fixed range of temperature but occurred over a range, the position of which depended on the speed and mode of deformation.

Iron and Steel Institute.

THE DILATATION OF CAST IRONS DURING REPEATED HEATING AND COOLING.

BY PROFESSOR J. H. ANDREW, D.Sc., AND ROBERT HIGGINS, B.Sc.,
A.R.T.C. (GLASGOW).

THE work on the growth of cast irons by Outerbridge,⁽¹⁾ Carpenter and Rugan,⁽²⁾ Campion and Donaldson,⁽³⁾ and Andrew and Hyman,⁽⁴⁾ was all carried out in the same manner, namely, by repeatedly heating bars of iron to a predetermined temperature and measuring the change of volume on cooling after each successive treatment. This method, whilst it gave a measure of the actual change in volume undergone by the specimens, gave little or no indication of the mechanism of the reactions involved in such changes, even when supported by micro-examination. It was accordingly decided to extend the investigation of this troublesome phenomenon in another direction, and to determine the variations in length undergone during the process of heating and cooling.

The method used was successively to heat and cool small rods of the selected material 0.875 inch in diameter and 2 inches in length in the dilatation apparatus, as described by Andrew and his co-workers.⁽⁵⁾ The only difference in the apparatus now used as compared with the fore-mentioned was that a dilatometer of larger dimensions was employed. The flexible disc in the present form was 12 inches in diameter; this increased diameter gave greater sensitivity.

The larger size of dilatometer was found to be more troublesome to make perfectly watertight. This difficulty was overcome by the insertion of a thick rubber ring between the flexible disc and the body of the apparatus, the bolts being so adjusted as to bring about as far as possible an equal distribution of pressure over the whole area of the rubber ring. All glass and metal joints were cemented with a mixture of litharge and glycerine, and finally every joint, metallic or otherwise, was coated with a thick layer of varnish.

Solid specimens with a small hole drilled for the insertion of a thermocouple were used throughout.

In the experiments of Andrew and Hyman, it was noticed that a large percentage of the increase in volume was due to the thick coating of oxide that formed over the surface of the specimens. Such a coating, if formed at the ends where the silica tube conveyed the expansion motion to the diaphragm, would greatly militate against the accuracy of the method. Accordingly, small discs of transparent quartz were inserted in between the specimen and the silica rods that butted up against it. This almost completely prevented even superficial oxidation of the ends. It was also noted that the specimen as a whole was only slightly scaled, the relatively enclosed space largely preventing this. In addition, each specimen was cleaned before each heat to remove the small amount of oxide formed.

The thermocouple, which was platinum—platinum-iridium, was connected with a sensitive mirror galvanometer through a Tinsley vernier potentiometer, which gave readings accurate to $\pm 0.2^\circ \text{C}$. On account of the large number of irons chosen for the purpose of experiment it was decided to limit the number of heats to twenty-one, and only to take readings for alternate heatings and coolings. Micro-specimens in the form of cylinders, 0.75 inch in length and 0.875 inch in diameter, were treated in exactly the same manner and at the same time as the dilatation specimens in another furnace.

The maximum temperature for heating was the same in every case, namely, 900°C . After attaining this temperature, soaking was allowed to proceed for three hours.

PREPARATION OF SAMPLES.

For the preparation of the cast irons the following materials were used :

	C.	S.	P.	Si.	Mn.	Fe.	Al.
Ferro-manganese .	6.50	0.01	0.25	0.75	78.0	...	...
Ferro-phosphorus .	0.03	0.20	18.6	0.86	0.1	80.6	...
Ferro-silicon .	0.09	0.03	0.04	48.7	0.8	50.0	0.5
Swedish pig iron .	4.20	trace	0.015	0.61	trace	...	...

The charges, of about 7500 grammes in weight, were melted in a plumbago crucible by means of a Méker gas injection furnace; the Swedish pig was melted first, as rapidly as possible, after which the necessary additions were made.

When completely melted all dross was skimmed off, and the metal poured through a small tun-dish into a hot sand-mould measuring 14 inches deep by 2.5 inches in diameter. A head of 3 inches diameter and of the same depth was allowed. The castings remained in the mould for twelve hours before stripping. Before machining to size 25 per cent. was cut from the top, and 5 per cent. from the bottom of the bar; this was discarded. Thus, specimens absolutely free from any chill effect were obtained.

In all, ten castings were made, the first series varying in manganese, and the second series varying in phosphorus. A silicon content of 1.5 per cent. was aimed at in order to represent as far as possible practical conditions.

The analysis of the finished bars was as follows :

No.	Si.	Mn.	P.	G.C.	C.C.	T.C.	S.
2	1.52	0.036	0.029	2.45	1.9	4.35	0.013
3	1.51	0.971	0.025	2.00	2.43	4.43	0.009
4	1.40	2.090	0.019	1.59	2.57	4.16	0.010
5	1.30	3.140	0.030	1.22	2.87	4.09	0.009
6	1.45	4.120	Not estimated		Not estimated		
7	1.41	5.450					
P1	1.51	0.01	1.30	2.20	1.44	3.64	0.013
P2	1.53	0.016	2.04	2.00	1.53	3.53	0.016
P3	1.46	0.25	2.78	2.20	1.58	3.78	0.028
P4	1.40	0.28	4.20	2.50	0.84	3.34	0.013

All the phosphorus specimens were machineable; of the manganese series Nos. 6 and 7 had to be ground to size.

MANGANESE SERIES.

The dilatation curves for each series have been plotted on Figs. 1 to 10 (Plates XIII. and XIV.), and they will be considered in their order of number.

Iron No. 2.—A glance at these curves in Fig. 1 is sufficient to show the extremely intricate nature of the changes undergone by cast iron upon repeated heating and cooling to and from 900° C.

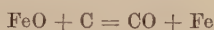
Not only is there a marked variation from one curve to another, but there is a decided periodicity with respect to the actual expansion undergone in each alternate treatment, as measured by the length of the vertical axis.

The first curve is normal, and indicates the usual contraction on heating and expansion on cooling at the critical point, which occurred at 800° C. on heating and cooling respectively. It will also be noted that a small contraction occurred on soaking; this shrinkage, although but slight in the present case, was found to be very marked in certain instances. The contraction may be due to several causes—namely, (1) to partial solution of the graphite; (2) to oxidation of graphite causing porosity, which, under the conditions of the slight pressure to which the specimen was subjected, might bring about a compression; (3) to some change in the oxide material formed, either of a chemical nature or solution or deposition of the same; (4) to the evolution of gases. It cannot be due to graphitisation, which would cause an expansion. In the third heat there was a net contraction on cooling, and a large diminution in the size of the critical points both on heating and cooling. The fifth heat showed the first real evidence of graphitisation on cooling, marked by an appreciable expansion, which started at the critical point and persisted over a wide range of temperature.

At the seventh heat there was an abnormal expansion on heating. This may be due to either further graphitisation or to oxidation of the iron, due to the air percolating through the graphite flakes.

Since the greater part of the graphitisation had taken place by this time, it is probable that the latter cause predominated, although both reactions may be contributory causes. The ninth heat was similar to the seventh, and at the eleventh heat there was again a large expansion on heating. On soaking a marked contraction occurred, the final state on cooling being more contracted than before heating. Previous to the eleventh heat there were no signs of any pearlite in the iron, so that the increased expansion must be attributed to oxidation, which was found by Andrew and Hyman to precede decarburisation. The spaces occupied by the graphite originally would at this period of the treatment be filled with a mixture of iron oxide (FeO and Fe_3O_4) and graphite, the

oxide surrounding the graphite. On soaking, the FeO would dissolve in the iron to a limited extent and diffuse through the mass, oxidising the particles of temper carbon present. The oxidation of the flaky graphite might or might not produce alteration in volume, but the oxidation of the temper carbon would cause a contraction due to carbon being replaced by finely divided iron, which would eventually become welded to and continuous with the mass. This reaction would take place according to the equation—



with liberation of CO, which on account of the porosity of the material would be easily expelled.

After the eleventh heat there was an appreciable diminution in the coefficient of expansion. From the thirteenth to the nineteenth heat the curves must be regarded simply as dilatation curves of a highly oxidised iron.

The nineteenth curve is, however, of particular interest. The iron at this stage, being practically devoid of carbon in any form, suddenly expanded on cooling, the expansion, which began at 720° C., continued over a wide range of temperature. This change must be due in some way to the oxide material; it may either be due to separation of oxide from solution, or to some reaction such as $\text{Fe}_3\text{O}_4 + \text{Fe} = 4\text{FeO}$, which is alleged by some to take place on cooling. Since, however, on analysis the separated oxide was found to be almost pure magnetic oxide this suggestion is difficult to believe, and the most probable hypothesis is that excess oxide, of the nature of FeO, has dissolved to an appreciable extent on soaking at the high temperature, only to separate again on cooling. If this be correct, the contraction at 900° C. on soaking must be attributed to solution of oxide. The dissolved oxide, it is assumed, would be in the nature of FeO rather than Fe_3O_4 .

Iron No. 3.—This iron represents a fairly normal type, with about 1·0 per cent. of manganese. The curves for this specimen were of a similar type to No. 2 iron. The increased quantity of combined carbon is manifest in the first curve, the contraction on heating and expansion on cooling being greater than in No. 2. The marked contraction on soaking on the first heating could only have been brought about by resolution of graphite in the iron, and

this, as is seen, was followed on cooling by a eutectoid change of considerable magnitude. In the fifth and seventh heats graphitisation would appear to have taken place both on heating and on cooling—indeed, from the micro appearance of the specimen at this juncture combined carbon was entirely absent. After the seventh heat all reactions are concerned with oxidation of the iron and elimination of free carbon. The very large expansion at the eleventh and thirteenth heats is significant of rapid oxidation of the iron on heating, and the contraction on soaking, of elimination of carbon by oxidation. By the nineteenth heat the carbon had almost disappeared, and on soaking the oxide was dissolved to a greater amount, only to be deposited on cooling, causing expansion. The twenty-first heat gave a normal curve for the highly oxidised material.

Iron No. 4.—On account of the considerable increase of the manganese content, resulting in an increased amount of free carbide, it was only to be expected that the progressive changes would be more pronounced, and extend over a large number of heatings and coolings. In the cast material large patches of cementite, presumably composed of manganese and iron carbides, were found on micro-examination. These patches gradually disappeared as the heatings progressed, but they did so individually and completely. In other words, when a cementite patch started to decompose the decomposition soon became complete, other patches however remained unaltered. For this reason repetition effects are noticeable features in the curves for the high manganese cast irons. The large expansion on heating, which increased to the eleventh heat progressively, was again thought to be due to graphitisation, as was also the expansion on cooling beginning from the critical point. The reason for this repetition effect has already been commented upon, and was stated to be due to the decomposition occurring in patches. This interesting fact would seem further to substantiate the theory of Honda ⁽⁶⁾ in that the oxygen of the air played an important part in the formation of graphite from cementite.

After the twenty-first heat most of the free carbon had disappeared and large flakes of oxide were present. Small patches of cementite were still visible however.

The fact that the changes which occurred in the high manganese

series were in many cases associated with isolated patches, brings to light the possibility of having a number of different reactions all taking place at the same time, producing either similar or dissimilar effects in the nature of dilatation.

The smoothness of the heating curves was very marked, but the slight kinks on cooling must not be regarded as all representing definite changes, for in a heterogeneous mass, such as cast iron, slight changes are almost bound to take place at varying temperatures on cooling.

Iron No. 5.—The curves for this iron are of a similar nature to those of No. 4. As the manganese increased it was noted that the contraction on soaking became less. From the first heat it was evident that the greater part of the carbide was in the form of iron-manganese carbide, the pearlite carbide, judging by the magnitude of the critical point, being less than in No. 4. The extraordinary amount of graphitisation on cooling as seen in the curve for the seventh heat was a very marked feature of this series. It will be noted that when the heating curve showed a smaller expansion than usual, the expansion on cooling was greater. The absence of contraction on soaking might be attributed to the smaller solubility of manganese oxide, which must form, as compared with the iron oxide.

Although manganese is more readily oxidised than iron, it would appear that the manganese carbide is less so. Decomposition of Mn_3C can only give as products free manganese and carbon, both in the finely divided form. Manganese in this state of division would be expected to be easily oxidised. That this is so is apparent from the curves, which show an exceptionally large expansion on heating at certain periods, as would undoubtedly result from oxidation of free manganese.

Irons Nos. 6 and 7.—Since irons Nos. 6 and 7 were fairly similar with respect to composition they will be considered together. The most noticeable features were—the large expansion on heating, the complete absence of any definite critical point on cooling after the first few heats, and the fact of the greater number of heats being necessary to produce the large expansion due to graphitisation on cooling. The contraction on soaking noted towards the end curves of both series is difficult to explain, but when it is recalled that these two irons were of an even more patchy

nature than the former ones, it is obvious that this contraction may be due to local action at certain particular parts of the material. It might be due to partial solution of the carbon, to partial solution of the oxide, or to any of the reasons previously mentioned. After the twenty-first heat both samples contained a considerable amount of free cementite, patches of free oxide in the form of flakes, and in certain places flakes of graphite.

PHOSPHORUS SERIES.

The phosphorus series of irons presented many peculiarities, some of which are extremely difficult to explain. The total expansion in the phosphorus irons was considerably less than that of the manganese irons.

Iron No. P1.—The heating curve in the first heat showed a marked break at 800°C ., otherwise the expansion was normal. On cooling after this heat a very large expansion took place at 720°C ., the specimen at the completion of this expansion being of greater length than it was at 900°C . No further change was noted on further cooling to ordinary temperature.

After the seventh heat no change on heating was noted.

On cooling for the third time, the expansion at 720°C . was considerably less, whilst in the fifth and seventh heats it was spread over a considerable range of temperature. The large expansion at the first heat, on cooling, was undoubtedly due to the almost complete graphitisation of the free carbide of iron, as distinct from the carbide in the phospho-carbide eutectic, and it is seen that after the seventh heat this was completed.

On heating for the ninth time a slight expansion on soaking was recorded, and a large expansion on cooling; this has been assigned as being due to solution of the phosphide on soaking, liberating free carbide which, being surrounded by the phosphide, was protected. The carbide of the phosphide eutectic would go into solution in the iron, only to be deposited again on cooling in the form of graphite.

After the ninth heat, a remarkable change is noted in the contour of the curves. Soaking at 900°C . had brought about a very marked contraction. This contraction, which was obtained every time on soaking, was invariably followed by an expansion

of varying magnitude, which began at about $520^{\circ}\text{C}.$ on cooling. The authors are only able to advance one reason for this relatively large contraction—namely, that it is due to phosphide of iron liquating and filling up the spaces previously occupied by the graphite. This explanation is supported by micro evidence. The expansion at $520^{\circ}\text{C}.$ is in all probability due to some change in the phosphide itself, possibly to the deposition of some substance which at the higher temperature was dissolved in it.

Iron No. P2 is of particular interest. The first heating and cooling curves are similar to P1, the expansion on cooling being less on account of a greater amount of the combined carbon being in the form of the phosphide carbide eutectic. Whilst the changes occurring in this sample are, generally speaking, similar to those of P1, the amount of contraction on soaking in the later heats was most abnormal.

Iron No. P3.—Cooling after the first heating brings about the usual expansion at $720^{\circ}\text{C}.$, smaller in magnitude than in any of the previous samples, on account of an increase in the amount of the phospho-carbide eutectic. All critical points on heating disappear after the fifth heat, whilst the cooling curves indicate a marked transformation at about $520^{\circ}\text{C}.$, due, as has been suggested, to a change in the phosphide constituent. The contraction on soaking in the later heats is far less marked than with either No. P1 or P2.

Iron No. P4.—The main feature with regard to this iron lies in the small expansion that persists on soaking, up to the eleventh heat. This, along with the fact that on cooling the change point at about $720^{\circ}\text{C}.$ was distinct even after the fifteenth heat, further supports the contention that soaking has produced the liberation of the iron carbide from the phosphide eutectic and its solution in the iron. The marked contraction on soaking was found only towards the end numbers of heats.

The reason why the contraction effect is delayed by the high phosphorus content is thought to be due to the slower oxidation of the graphite delaying the formation of voids into which the phosphorus would liquate. Until the graphite has been completely oxidised out the maximum contraction would not be observed.

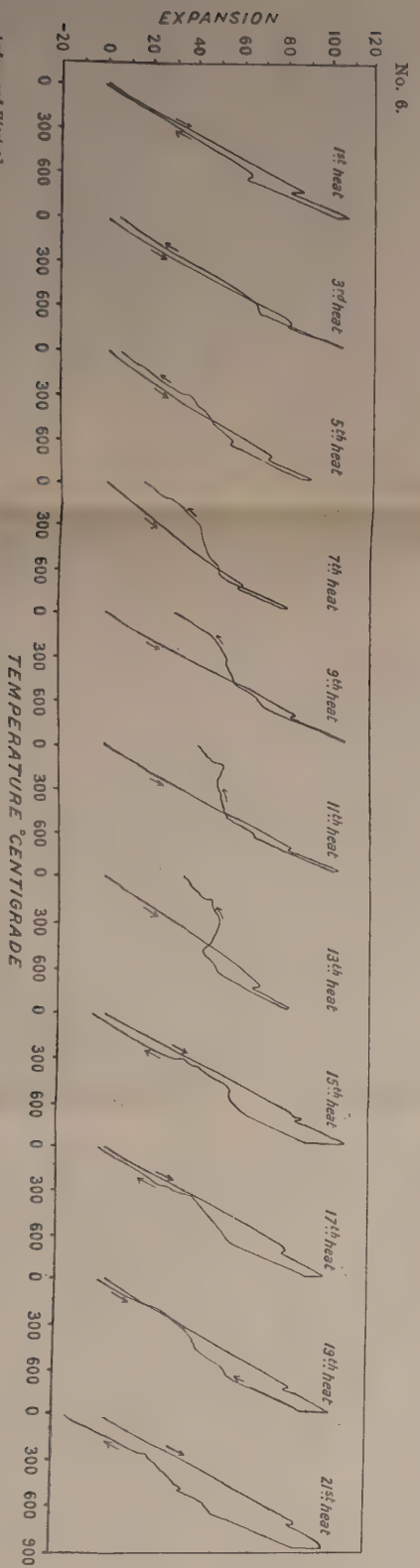
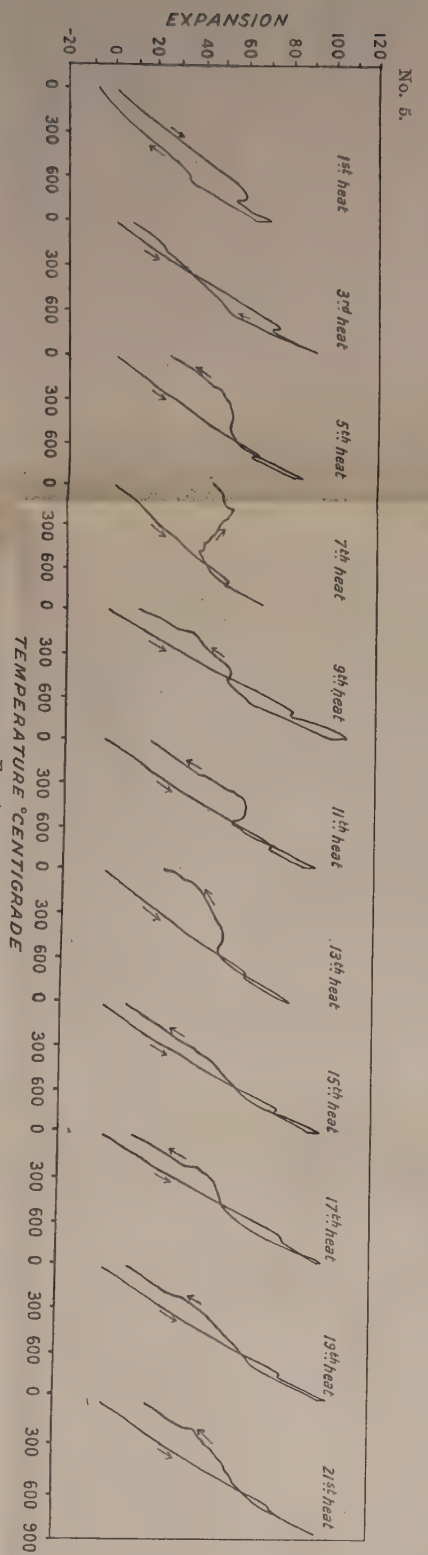
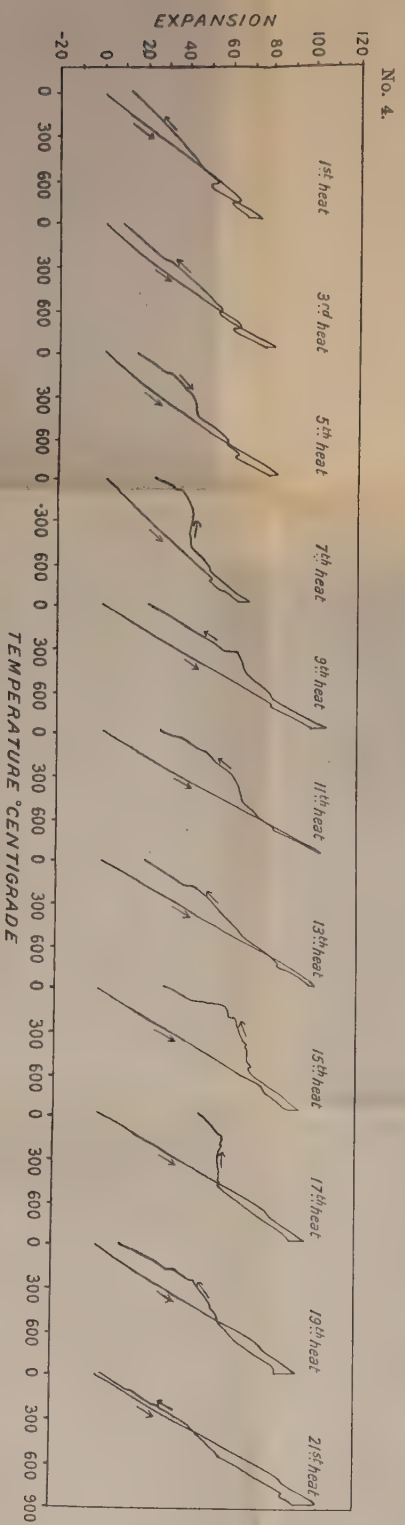
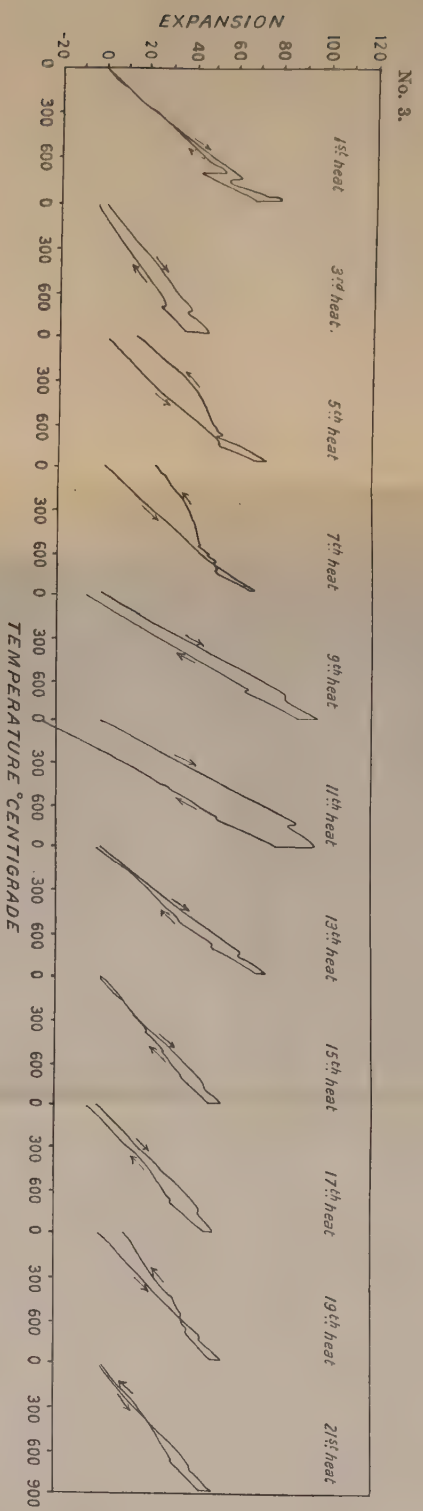
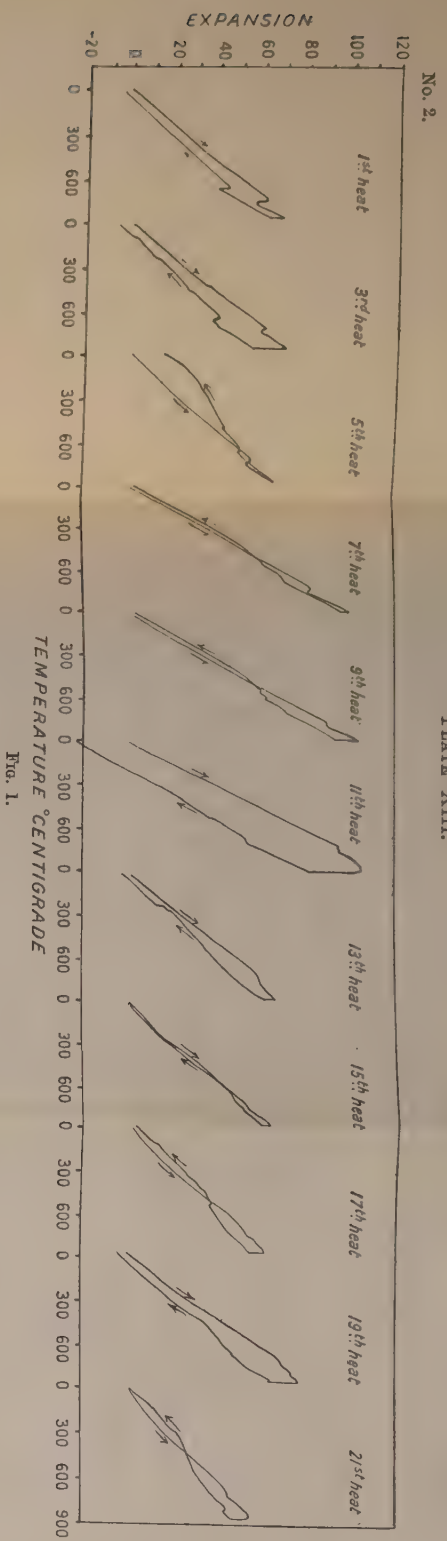
MICROSTRUCTURES.

Although a very large number of photomicrographs were taken, only sufficient to illustrate the different types of structure met with will be included.

Micrographs Figs. 15 and 16 (Plate XV.) are typical of a completely oxidised specimen. Fig. 15 is etched and Fig. 16 unetched. The oxide material is seen to fill completely the spaces originally occupied by the graphite, whilst small particles of oxide are disseminated through the mass. The larger masses in certain cases had the appearance of mixed oxides.

It was quite usual to find in the manganese series isolated patches, in which complete oxidation had taken place early with respect to the number of heats. Micro Fig. 17 shows one of these patches found in iron No. 6 after the fourth heat; it also shows the breakdown in grain-size due to the rapid diffusion that must have occurred in the production of this structure. Patchiness of structure is again illustrated in micro Fig. 18, which shows a patch of undecomposed material in iron No. 7 after the eighth heat. The massive cementite and pearlite are clearly evident.

Micros Figs. 19 and 20 are of iron No. 7, the eleventh heat. Fig. 19 is the structure of a sample as quenched on attaining 900°C ., whilst Fig. 20 is of the same iron at the same heat as quenched after soaking at 900°C . for three hours. The difference between these two structures is that in Fig. 19 the graphite flakes are unchanged, whilst in Fig. 20 they are intermingled with oxide material. From the dilatation curves it will be seen that this iron, on soaking at 900°C . during the eleventh heat, underwent a marked contraction. This micro is further confirmation of the suggestion made that the contraction was due to the small particles of oxide dispersed throughout the iron diffusing and coalescing in the spaces occupied or left by the graphite. This diffusion effect is more clearly seen from Figs. 21 and 22 (Plate XVI.), No. 2 iron, eleventh heat. Both have been quenched from 900°C ., but the specimen shown in Fig. 22 was soaked at 900°C . for three hours, whilst that in Fig. 21 was allowed to attain that temperature and immediately quenched. The extreme fuzziness, due to small particles of oxide seen in Fig. 21, has been almost completely cleared by the soaking treatment. The large expansion which



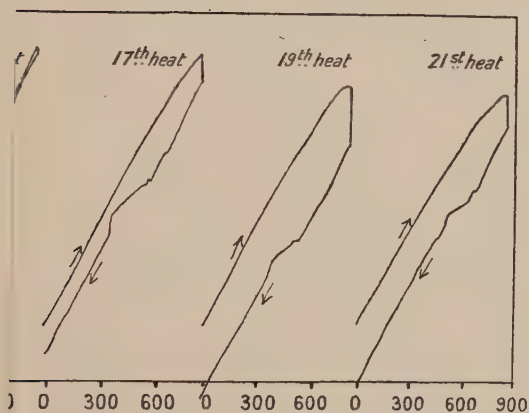
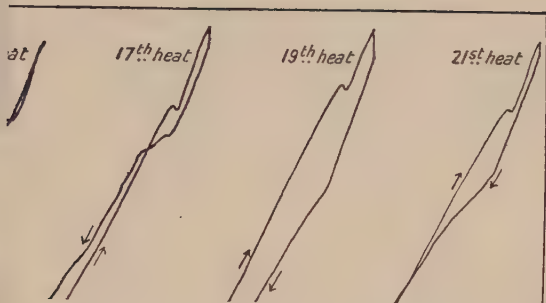




FIG. 15.
No. 3. 20th heat. Etched. $\times 75$.



FIG. 16.
No. 3. 20th heat. Unetched. $\times 75$.

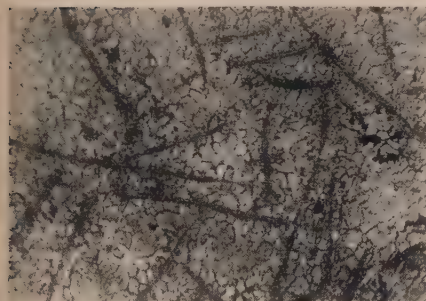


FIG. 17.
No. 6. 4th heat. Etched. $\times 75$.



FIG. 18.
No. 7. 8th heat. Etched. $\times 75$.



FIG. 19.
No. 7. 11th heat. W.Q. 900°C. Before soaking. Etched. $\times 75$.



FIG. 20.
No. 7. 11th heat. W.Q. 900°C. After soaking. Etched. $\times 75$.

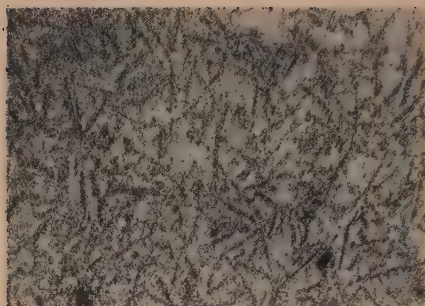


FIG. 21.
No. 2. 11th heat. W.Q. 900°C. Before
soaking. Etched. $\times 75$.



FIG. 22.
No. 2. 11th heat. W.Q. 900°C. After
soaking. Etched. $\times 75$.



FIG. 23.
No. 5. 7th heat. W.Q. 800°C. After
soaking 3 hours at 900°C. Etched. $\times 75$.

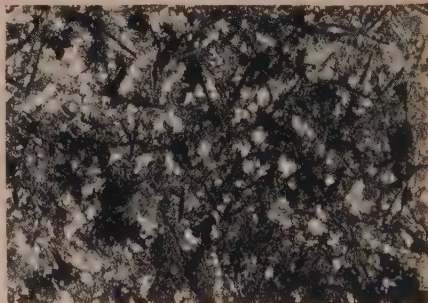


FIG. 24.
No. 5. 7th heat. Slowly cooled. After
soaking 3 hours at 900°C. Etched. $\times 75$.



FIG. 25.
No. P1. 1st heat. W.Q. 800°C. After
soaking 3 hours at 900°C. Etched. $\times 75$.



FIG. 26.
No. P1. 1st heat. W.Q. 400°C. After
soaking 3 hours at 900°C. Etched. $\times 75$.

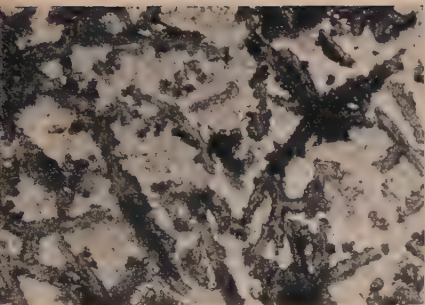


FIG. 27.
No. P2. 21st heat. Etched. $\times 75$.

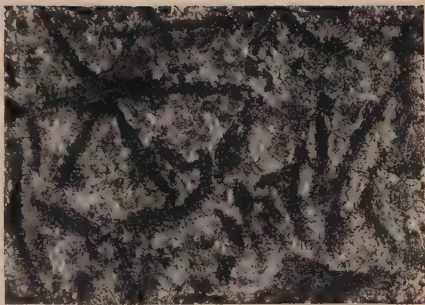


FIG. 28.
No. P4. 21st heat. Etched. $\times 75$.

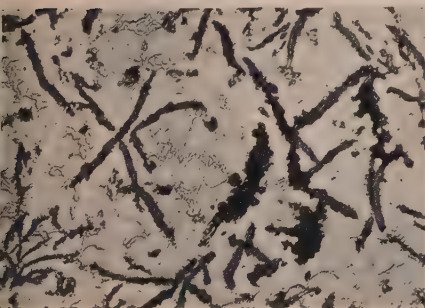


FIG. 29.
No. P4. 21st heat. Unetched. $\times 75$.

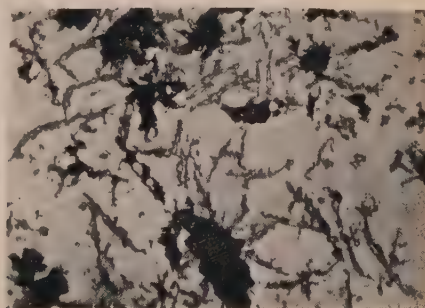


FIG. 30.
No. P3. 16th heat. Unetched. $\times 75$.

took place in iron No. 5 at the seventh heat on cooling is clearly explained by micros Figs. 23 and 24. Fig. 23 shows the structure after quenching from 800°C . following upon soaking at 900°C . for three hours, and Fig. 24 that of the same iron at the same heat as soaked at 900°C ., but allowed to cool slowly to ordinary temperature. The graphitisation of the carbide is quite evident.

Fig. 25 shows the structure of P1 as quenched from above the critical point on cooling. The specimen had not been previously heated. The structure is seen to consist of martensite and graphite. As illustrating the graphitisation on cooling slowly through the critical point, Fig. 26 shows the same iron also heated for the first time, but allowed to cool to 400°C . before quenching. The increase in the amount of graphite and absence of pearlite is very apparent. Fig. 27 (Plate XVII.) depicts the structure of P2 after the twenty-first heat (etched). The large flakes have every appearance of being composed of FeO and phosphide. Fig. 28 is of P4 after the twenty-first heat, but in the etched state. The blackness of the flakes suggests that a certain amount of graphite is mixed with the phosphide as well as some FeO . The same structure unetched is shown in Fig. 29, in which the phosphide is easily discernible. Fig. 30 illustrates very well a stage in the process of liquation of the phosphide. This structure, which was unetched, shows flakes of oxide and phosphide, in which the two constituents are in places distinct and separated.

During the period in which rapid solution of phosphorus took place small grains of exactly the same pattern as shown in micro Fig. 17 were always observed.

DISCUSSION OF EXPERIMENTAL RESULTS.

A remarkable feature common to all the dilatation curves lies in the diminutive size of the true critical points, as distinct from the larger changes due to graphitisation. After a relatively small number of heats it becomes increasingly difficult to determine exactly what may be styled as a critical change in distinction to the small, sudden variations in length, brought about most probably by local reactions within the specimen. In view of the constancy of certain deflections throughout every series, it is possible to distinguish the real from the apparent, and to state

quite definitely that in all the irons experimented with only one true critical point on heating, and one on cooling, pertained. In the manganese series the variation in temperature as the manganese increased amounted at the most to 50° C.

From the work of Charpy and Thenard,⁽⁷⁾ and of Honda and Murakami,⁽⁸⁾ it would seem that a silicon content of 1.5 per cent. is sufficient to obliterate all critical points in a pure iron excepting the magnetic or A2 change, whilst the work of Hanson and Colbeck⁽⁹⁾ would appear to show that manganese, when added to an iron-silicon alloy, has but little effect, silicon being the predominating element.

The single critical point observed on heating and on cooling in all the irons must then be the A2 change, unaffected by manganese, excepting in the initial stages, where pearlite forms on cooling. The absence of any A3 or A1 change naturally implies that on heating to 900° C. the iron never becomes transformed into the γ state, and this conception receives considerable support from the experimental data.

No pearlite was detected in any of the samples after they had been heated for a second time to 900° C., usually one heating was sufficient to graphitise completely all the carbide originally existing as pearlite. Free cementite, and in the phosphorus series large patches of the phospho-carbide eutectic, were clearly visible on micro-examination.

It is suggested that the following reactions take place on cooling an iron containing 1.5 per cent. of silicon from the melt :

Immediately after freezing the alloy will consist of free cementite and silico-austenite. On further cooling, graphitisation will take place according to the stable iron-carbon diagram, until the eutectoid point is reached, when pearlite will form. Any free manganese-iron carbide, or free phosphide-carbide eutectic, will remain as such throughout the cooling.

Upon heating again, assuming the iron to remain in the α state to the upper limit of temperature under consideration, viz. 900° C., iron carbide would gradually go into solution in the α -iron, the solubility increasing with temperature. Simultaneously with solution there would occur graphitisation, which would take place progressively on heating up to 900° C. Upon cooling again no change would occur until the A2 point was reached, which, whilst it cannot perhaps be regarded as an allotropic change, must be in

the nature of a change in the atomic or electronic configuration, and is apparently sufficient to bring about a complete breakdown of the dissolved carbide and free carbide of iron, with the formation of graphite. That masses even of manganese-iron-carbide break down completely under these conditions is evident from a micro-examination of a specimen quenched previous to and after the critical change. The experimental evidence points to some solubility of silicon in both the carbide of iron and double carbides of iron and manganese, also to the fact that the presence of finely divided or temper carbon rapidly initiates their breakdown. In the phosphorus series, graphitisation in iron P1 was even more complete at the critical point, which in the first cooling curve is seen to give rise to a relatively enormous expansion. Phosphorus in solution has evidently a "salting-out" effect, incidentally causing an apparent increase in the silicon content, thus increasing the activity of that element with respect to its graphitisation propensities. The phospho-carbide constituent would seem, however, to be a relatively stable body unaffected by silicon. This is to be expected when it is considered that this eutectic freezes at a temperature considerably below that at which all the silicon has become solid, and on this account will be free from the graphitising element.

Graphitisation does not, however, serve to explain all the reactions involved in the growth of cast iron; oxidation of the iron plays an almost greater part in the actual increase in volume. At the temperatures concerned, oxygen has a greater affinity for iron than for carbon, and it was always found that it was not until a considerable amount of Fe_3O_4 was formed that decarburisation proceeded with any avidity. In immediate contact with the unchanged iron there would undoubtedly be the lower oxide (FeO), which at the higher temperatures would diffuse to a limited extent into the metal and oxidise the small particles of temper carbon previously formed, giving rise to a further change in volume and to the formation of carbonaceous gas. Whether the gases thus formed are responsible for any increase in volume is doubtful, as their evolution from the iron would be aided by the porous nature of that material. Solution of ferrous oxide would be expected to give an increase in volume. Further, in the phosphorus series, solution of the phosphide would be followed by graphitisation, and this latter reaction, producing a carbonless silico-ferrite, would cause

an expansion. Diffusion of the phosphide would, by depriving the carbide of the phospho-carbide eutectic of its protective action, immediately bring about the graphitisation of that carbide, on cooling.

Contraction would be brought about by the following reactions :

1. By deposition of oxide of iron from solution, there would be a tendency for this oxide to diffuse towards the massive oxide segregates, which filled the spaces originally occupied by the graphite, and to be deposited on them.

2. By liquation of the phosphide material. It was found that the phosphide showed a marked tendency to diffuse into and partially fill the hollow spaces formed on oxidation of the graphite, and also into the porous graphite itself.

3. By oxidation of the carbon, either in the form of graphite or in the combined state. Oxidation of the graphite would create voids, and it is possible that the specimens being under slight compression might tend to contract. Oxidation of the combined carbon would bring about an immediate contraction.

It was only to be expected that the centre of the specimens was less oxidised than the outside portions and the metal adjacent to the outside. This non-uniformity made a true chemical analysis impossible, since the zones were so widely different and the lines of demarcation abrupt. Analysis did show, however, that with the phosphorus series complete decarburisation had not taken place by the end of the twenty-first heat, excepting in the case of P1. Phosphorus would be expected materially to affect the iron with respect to oxidation, serving, when in solution in the iron, to protect it appreciably. Indeed, it was found that the higher the phosphorus content of the metal the less became the amount of that constituent which could be definitely termed oxide, and in the later numbers the structure, as determined by the microscope, revealed a constituent which had all the appearances of mixed phosphide and graphite. Reasoning on this basis, the large contraction on soaking obtained in P2 may be attributed to the more or less complete oxidation of the carbon directly by the air and the filling up of the spaces by phosphide material. In the high phosphorus samples, however, liquation of the phosphide would be expected to take place more readily, producing two effects—namely, the freeing of iron carbide, which on decomposition would bring about an expansion ; and, secondly, liquation of

the phosphide into the graphitic material itself, thus partially protecting it from rapid oxidation. Phosphorus would appear to have a delaying action, but in every case would eventually produce a contraction.

Manganese, whilst it has a stabilising effect on the carbide, makes the iron more prone to oxidation, whilst the product of decomposition of manganese carbide, namely, manganese and carbon, would be most readily oxidised. That this was the case was evident from the rapidity with which the manganese iron carbide, once it had decomposed, became oxidised.

In Figs. 11 and 12 there are plotted the growth figures, measured in terms of the dilatometer (34 centimetres are equal to an actual expansion of 0.01 of an inch on 2 inches). In the manganese series (Fig. 11), it is seen that in every case the expansion which takes place in the preliminary heatings shows a tendency to cease after a certain number of heats and become a contraction. There is no relation between chemical composition and growth shown by these curves—growth is, however, dependent upon so many factors that in a heterogeneous material, such as cast iron, it is not to be expected. Growth must, for instance, be dependent upon the amount of graphite, upon the volume and size of the graphite flakes, upon the form of combination of the manganese, and other variable factors. Similar curves are shown for the phosphorus series (Fig. 12). The remarkable position of the curve for P2 relative to the others is inexplicable. The curves do, however, point to the delaying action of the phosphorus, for, with the exception of P2, the higher the phosphorus content the greater is the number of heats required to produce the same amount of contraction. Here, again, the rate of the reactions will depend upon the size and configuration of the graphite flakes, and upon the position and form taken up by the phosphorus with respect to the other constituents. An important conclusion of this work with respect to the choice of suitable materials to withstand heat is that if cast iron be selected it is imperative that the silicon content be low, a conclusion come to by Carpenter and others from practical tests. The addition of a carbide-forming element, whilst it would serve to stabilise the carbide, would in no way assist in preventing decomposition of the pearlite, silicon having the effect of immediately bringing about the graphitisation of carbide in solution the moment it tended to be deposited from solution in any form.

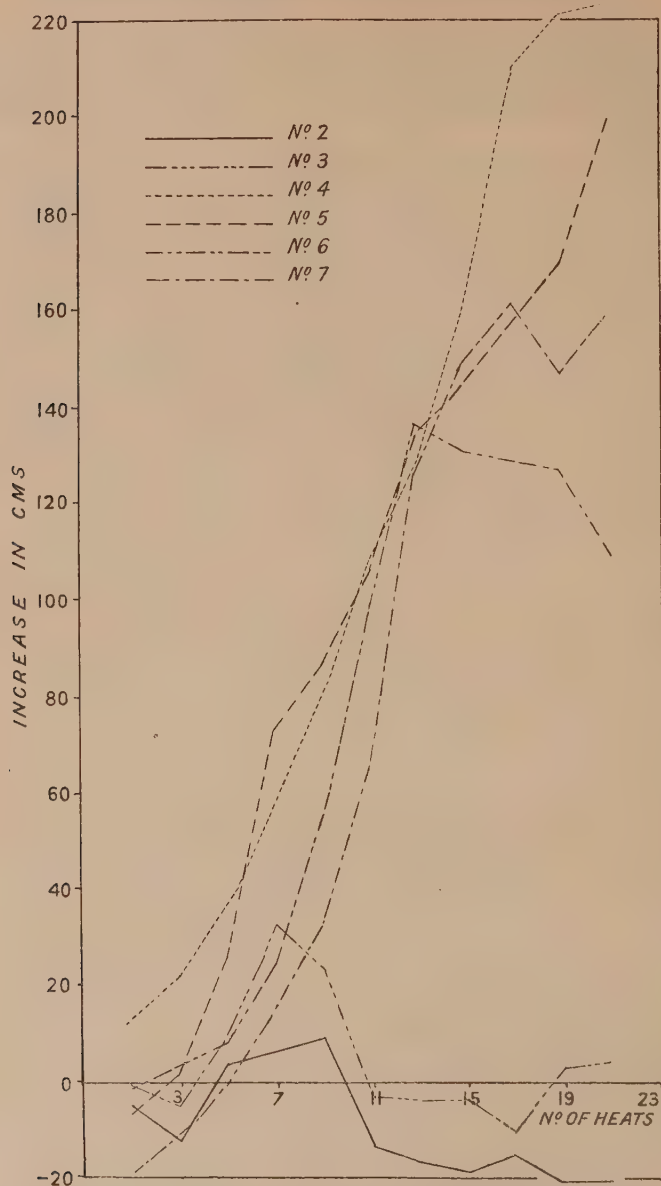


Fig. 11.—Increase on Length on Scale at 15° C. (summed).

The scleroscope hardness of all the specimens taken after the different heats are given in Figs. 13 and 14.

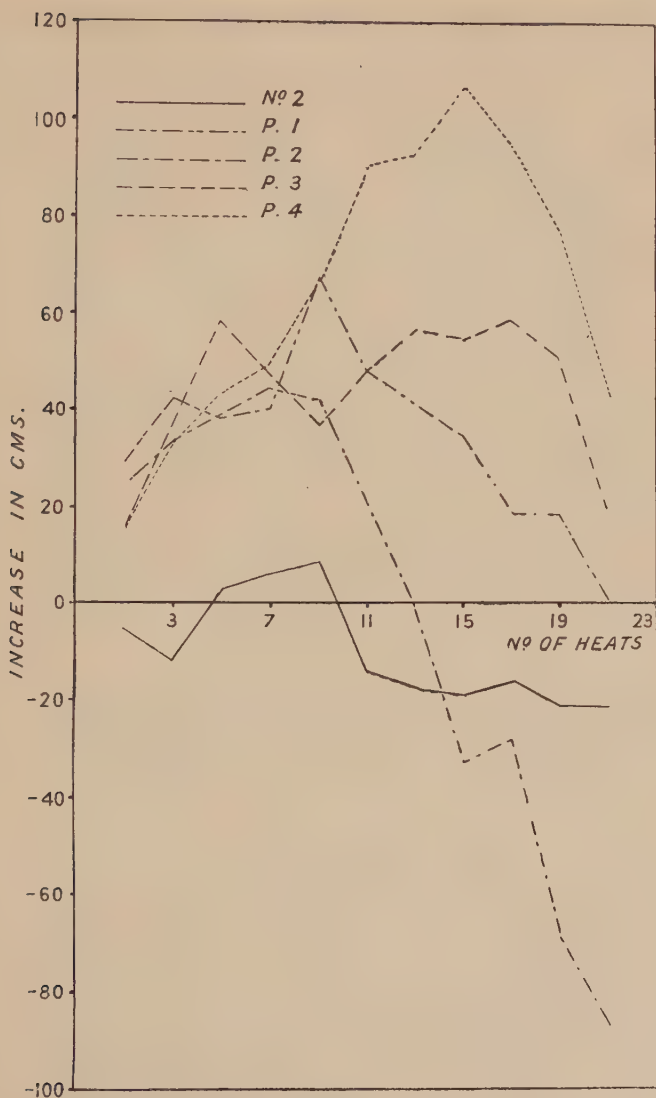


FIG. 12.—Increase on Length on Scale at 15° C. (summed).

SUMMARY AND CONCLUSIONS.

Dilatation curves have been taken of two series of cast irons, both of which contained approximately 1.5 per cent. of silicon.

In the first series the phosphorus was low and the manganese

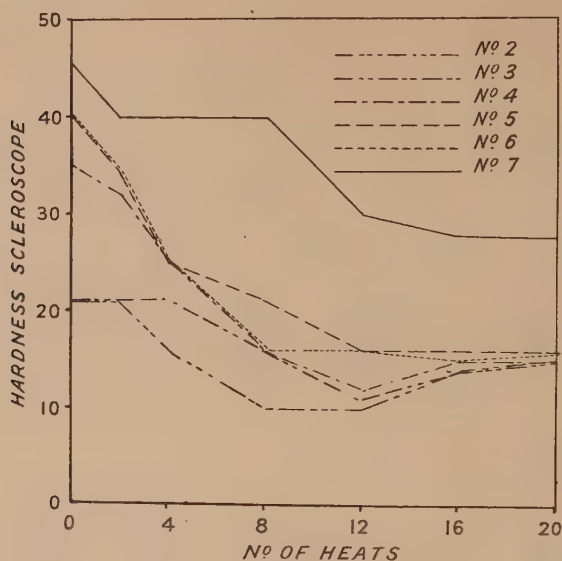


FIG. 13.

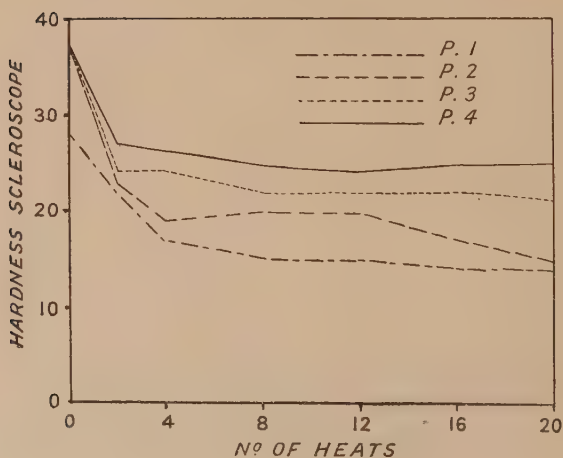


FIG. 14.

varied, and in the second series the manganese was low and the phosphorus varied.

It has been shown that a silicon content of 1.5 per cent. is

sufficient to cause graphitisation of nearly all the carbon in solution, as distinct from free carbon, after one or two heatings and coolings, and an explanation for this action has been given.

The number of heats has been limited to twenty-one, and the maximum temperature to 900° C. ; all the specimens were soaked at this temperature for three hours before allowing to cool.

The manganese series showed a large expansion on repeated heating and cooling, due to graphitisation and oxidation of the iron. Eventually the graphite was oxidised, and the spaces originally filled with graphite were eventually filled in with oxide of iron. Diffusion of FeO was found to bring about oxidation of the small particles of temper carbon.

In the phosphorus series increase in phosphorus increased the amount of growth, but in every case growth was followed by a contraction. Growth of the phosphorus irons has been explained as being due to graphitisation, and partially to oxidation of the iron. Contraction, it is suggested, was brought about by liquation of the phosphide of iron into the graphite flakes, and into the spaces formerly occupied by the graphite previous to its elimination by oxidation.

Phosphorus was found to protect the iron to some extent from oxidation. Solution of phosphide always followed graphitisation, on account of this element being more soluble in an iron containing no carbon than one containing carbon in solution.

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CORRESPONDENCE.

Mr. E. ADAMSON (Sheffield) wrote that the authors, in continuing their work on the growth of cast iron, again demonstrated their patience in dealing with detail. In replying to his (Mr. Adamson's) criticism of their paper at the May meeting of the Institute last year,¹ the authors stated that "the reactions taking place in the process of malleabilising were a direct contradiction of the theory put forward by the authors." That statement suggested that the authors were not looking at the question of expansion and growth in the most simple way. Like evolution, the process from the precipitation of carbon, say, first in white iron, starting with expansion on graphitisation, followed by expansion on growth of graphite, again followed by growth by oxidation, was a continuous process, and it would make it easier to understand if the authors considered the matter from that point of view.

In their previous paper, as also in the present one, the authors agreed with him (Mr. Adamson) that expansion—which in one sense might be called growth—took place through graphitisation and then growth of graphite, which was a ground of mutual agreement he wished to stress. For the moment he was not concerned with growth by oxidation.

In the authors' previous paper only three of the samples were white iron, the remainder being grey—about 90 per cent. of the total carbon being graphite. In the present paper, although it was not stated, they were dealing with white, mottled, and grey fractures, and even the grey fracture might possibly have shown very slight signs of mottle. It would have been better, therefore, in order to obtain strictly comparative data, to have commenced their research with a pure grey virgin hæmatite pig iron which could easily have been obtained, and then even with manganese 5.45 per cent. the probabilities were that all their initial fractures would have been grey, as would also their samples with the addition of phosphorus 4.2 per cent. As it was, not one of their samples represented a commercial cast iron. That was because they started with a base of white iron, and, as he (Mr. Adamson) had frequently pointed out, the addition of even a high percentage of silicon to white iron produced in the resulting sample a fine close grey fracture, whereas in a commercial pig iron with silicon 1.50 per cent. and sulphur 0.03 per cent. the fracture would have been perfectly grey, most probably an open grey with large graphite flakes.

He could not see any satisfactory reason for drawing a distinction between expansion or "stretch," in the one case caused by repeated heatings and coolings, and in the other by precipitation of carbon

¹ *Journal of the Iron and Steel Institute*, 1924, No. I. p. 463.

by annealing continuously, which the authors called "malleabilising." The same conditions of temperature and time in precipitation and growth of graphite applied in both cases, and the differences in the two methods were not ones of *principle* but of detail—*i.e.* differences in temperature and time in treatment. It was admitted that in annealing in the Réaumur process the carbon was oxidised at and behind the skin, whereas in the blackheart process the carbon was oxidised only on the skin, leaving the heart of the casting with its full total carbon precipitated as free carbon in the amorphous state. In the case of the blackheart the reason for the amorphous condition of the free carbon would be understood by reference to his paper on "Cast Iron under Heat Influence" given before the West of Scotland Iron and Steel Institute in the session 1918–19.

The annealing temperature in the blackheart process was lower than in the Réaumur, and in the latter with an annealing temperature of about 950° C. the influence of the higher temperature produced flaky graphite in the centre of the casting if the annealing was not perfect, which was one of the difficulties the malleable ironfounder had to contend with. Now, any consideration of expansion growth must be applied to all fractures of white, mottled, and grey irons, particularly as the authors had all those fractures in their samples. In their present paper the authors had come to the conclusion that the time as well as the temperature factor must be considered, which was what he (Mr. Adamson) had consistently stated during the whole period of his membership of the Institute, though it had, unfortunately, not been understood until quite lately.

In considering the expansion and growth of white iron, as had been shown in the two processes of malleabilising, the lower the temperature of precipitating free carbon from solid solution the smaller was the size of the free carbon in the amorphous condition, whereas at a temperature 200°–250° C. higher the free carbon was more of the flaky graphite variety.

In mottled iron the carbon was originally present not only in solid solution but also as free carbon, therefore in annealing by malleabilising or by repeated heatings and coolings whilst the carbon in solid solution was being precipitated the free carbon began to grow, and the longer the specimen was exposed to heat influences the larger the final flake.

With regard to grey iron, the free carbon would commence to grow from the first application of heat, whilst the remaining carbon in solid solution would gradually be precipitated.

Hence under these three different conditions of fracture one would expect differences in expansions of the samples under the same conditions of heating and cooling, owing to the differences in the percentages of graphitic carbon and combined carbon in the original fracture. The authors said that the fifth heat showed the first real evidence of graphitisation on cooling, marked by an appreciable expansion. Possibly if the authors would follow through the matter

of fracture—in other words, the conditions of carbon—in connection with their curves, it would account for some of the phenomena for which they had not suggested any explanation.

The authors' meaning was not quite clear with regard to the oxidation of flaky graphite and temper carbon. Did they mean by that the reduction in the percentage by oxidation? It was well known to all intelligent blast-furnacemen that white pig iron was more dense and of a higher specific gravity than grey pig iron, and conversely that an open No. 1 pig iron was the least dense and had the lowest specific gravity of any of the grades of iron between that and white, yet the grey pig iron was higher in total carbon—*pro rata* to the other impurities present—than was white pig iron. The same principle applied to the authors' samples. The percentage of carbon by weight, or even of carbon plus silicon, would not account for the difference in ratios of specific gravity between white and grey No. 1 iron, but Moissan's suggestion of intumescent graphite, which had been put forward by him (Mr. Adamson), would certainly offer a much more logical reason, rather than that suggested by the authors, namely, "oxidation of iron due to air percolating through the graphite flakes," which apparently presumed the percolation of air through solid graphite.

The further the authors investigated the question of cast iron the stronger would be their conclusion that it was a most intricate problem. The basis for any research must be substantially the same, and that could only be obtained by selecting virgin iron, since making up any analyses in the form of alloys gave no regular ratio and conditions of carbons and fractures.

Mr. C. E. PEARSON (Newcastle-upon-Tyne) wrote that he could not agree with the conclusion of the authors, that oxidation was the main cause of the increase in volume exhibited by cast iron on repeated heating and cooling. Experiments on growth, in various gaseous atmospheres, which he had recently carried out, had satisfied him that although oxidising conditions accelerated and, as a rule, increased the absolute amount of growth, yet under completely non-oxidising conditions it was possible for growth to occur to an amount which, in certain cases exceeded 60 per cent. of the total growth under oxidising conditions.

That was in accordance with the work of Okochi and Sato, who claimed to have found marked growth in hydrogen.

In their conclusions also the authors stated that no pearlite was detected in any of the samples after the second heating to 900° C.; and that only one critical point was detected in their dilatometer curves, which point they took to be the A2 change, hence they conceived that the iron in their samples never became transformed into the γ state. His (Mr. Pearson's) experience, using commercial grades of cast iron, several of which approximated in composition to iron Nos. 2 and 3 in that paper, and heating to the same temperature under

oxidising conditions, was that pearlite persisted even after forty heats in all the irons employed.

It would be most interesting if the authors could obtain dilatometer curves from irons heated in nitrogen or hydrogen atmospheres, since it might then be possible to distinguish between expansion due to internal oxidation and that due to any other factor.

The AUTHORS, in reply, thanked Mr. Adamson for his contribution. They would like to point out to him that their paper did not really concern itself with the question of malleabilisation of iron. In the malleabilisation process the temperature was kept relatively constant for a period of time, whereas in the experiments of the authors the specimens were repeatedly heated and cooled. With reference to Mr. Adamson's query regarding the oxidation of graphite, it was obvious that if oxidation of that substance did take place, the percentage of it would be reduced.

Mr. C. E. Pearson referred to the growth that occurred in a neutral or reducing gas, and mentioned that a considerable change in volume of the iron could be brought about by treatment in such atmospheres. It must not be overlooked that under certain conditions graphite had a high absorbing power for most gases, due to adsorption phenomena, and that repeated heatings and coolings in any gas other than an oxidising one would undoubtedly bring about a swelling of the graphite. With regard to the experiments quoted by Mr. Pearson, in which, after heating a commercial iron for a matter of forty heats, he still detected pearlite in his specimen, since he did not give any analysis of his iron it was impossible to make any statement upon that. All that could be said was that in the irons used by the authors the results stated were obtained.

They (the authors) welcomed Mr. Pearson's suggestion that they should take dilatation curves of irons in hydrogen and nitrogen atmospheres, and when time permitted they would do so.

Iron and Steel Institute.

THE MAGNETIC AND ELECTRICAL
PROPERTIES OF CAST IRON.

By J. H. PARTRIDGE, B.Sc. (HONS.) (UNIVERSITY OF BIRMINGHAM).

INTRODUCTION.

WHILE there is a vast amount of literature on the magnetic and electrical properties of steel, similar publications dealing with cast iron are only sparingly found. Cast iron has the advantage of cheap production, convenient casting and machining properties, higher specific electrical resistance, and consequently lower eddy current losses. Hence the use of cast iron could be greatly extended if its magnetic properties could be improved.

According to Parshall,¹ the permeability of cast iron is diminished if the cooling be too rapid, but it may be restored by annealing. Combined carbon is the most objectionable element. Graphite may vary between 2 and 3 per cent. without exerting any marked effect on the permeability. An excess of sulphur is an indication of an excess of combined carbon and inferior magnetic quality. Silicon in excess annuls the influence of sulphur and does not seem to be objectionable until its amount is greater than 2 per cent. The amount generally varies from 2·5 per cent. in small castings to 1·8 per cent. in large castings. Phosphorus in excess denotes an inferior magnetic quality of the iron, and it should be restricted to 0·7 or 0·8 per cent. Manganese, in the proportions generally found, has but little effect. Its influence becomes more marked in irons that are low in carbon.

In 1902 P. Reusch,² from a preliminary investigation, concluded that carbon content plays an important part in the magnetic value of a material, whilst silicon plays a part chiefly inasmuch as it precipitates graphite, which latter hinders the magnetic induction. Manganese did not seem to influence the magnetic induction unfavourably.

¹ *Minutes of Proceedings of the Institution of Civil Engineers*, 1895-96, vol. cxxvi., Part IV., p. 220.

² *Stahl und Eisen*, November 1, 1902, vol. xxii.

At Reusch's instigation, Dr. Nathusius investigated the matter and published his results in 1905.¹ Dr. Nathusius tried to explain the differences in magnetic properties from the chemical analysis, but since none of the elements were constant, he was not very successful. He concluded that the magnetic permeability was connected more with the structure than with the analysis. Dr. Nathusius stated that the size of the specimen did not influence the magnetic properties, and that cast irons with over 3 per cent. total carbon did not have an induction over 8000 C.G.S., whilst a specimen with only 1.8 per cent. total carbon attained an induction of 13,700 C.G.S. Specimens high in silicon have better magnetic properties than those poor in this element. No connection was found between the magnetic properties on the one hand and the electrical properties on the other. All the specimens used by Dr. Nathusius were annealed at 900° C. before testing. From a microscopical examination he concluded that all cast irons having high magnetic induction have the greater part of their carbon precipitated as graphite. Cementite is a sure indication of poor magnetic properties.

In 1901 Dr. A. Schweitzer² investigated the effect of aluminium on cast iron, the results of which showed that the magnetic properties become poorer the higher the content of aluminium (Dr. Schweitzer added up to 3 per cent. of aluminium).

In 1921 F. Goltze³ concluded that silicon, carbon, manganese, phosphorus, and sulphur decrease the permeability of cast iron and should be kept as low as possible.

EXPERIMENTAL.

American washed iron of the following analysis was used for the present investigation :

	First Supply. Per Cent.	Second Supply. Per Cent.
Total carbon	3.16	3.84
Graphitic carbon	nil	nil
Manganese	trace	trace
Silicon	0.046	0.03
Sulphur	0.016	0.02
Phosphorus	trace	trace

¹ *Stahl und Eisen*, Jan. 15, Feb. 1, Mar. 1, 1905, vol. xxv.

² *Elektrotechnische Zeitschrift*, April 25, 1905.

³ *Giesserei Zeitung*, February 1913.

The iron was melted in a 30-lb. salamander crucible, elements were added either in the metallic form or as ferro-alloys, and bars 12 in. \times 1 in. diameter were cast in sand-moulds. The bars were machined down to 1.128 centimetre diameter. The primary magnetisation curves were determined by using an Iliovici permea-

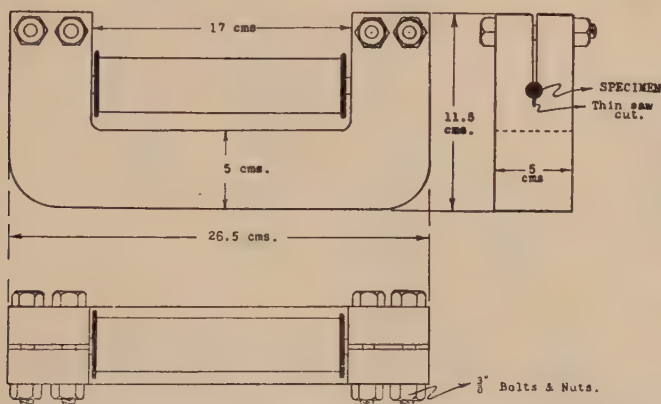


FIG. 1.

meter, and the hysteresis loops by the bar-and-yoke method. A sketch of the yoke is shown in Fig. 1.

The Effect of Silicon.—In order to determine the effect of silicon on the magnetic properties of cast iron, bars containing various percentages of this element were cast. The analysis of these bars is given in Table I.

TABLE I.

Specimen.	T.C.	C.O.	G.O.	Si.	Mn.
1	2.77	1.88	0.89	0.6	0.015
2	2.79	2.14	0.65	0.807	trace
*3	3.11	0.24	2.87	1.43	0.024
*4	2.95	0.35	2.6	1.97	0.025
*5	2.74	0.46	2.28	2.26	0.02
*6	2.675	0.28	2.42	2.46	trace
8	2.70	1.46	1.24	2.41	0.04
9	2.58	1.1	1.48	2.745	0.035
10	2.54	1.35	1.19	4.165	0.035

With the exception of those bars marked *, all bars were tested in the cast state, without even being annealed to remove machining



FIG. 2.

strains. The bars marked * were annealed at 900° C. for fifteen minutes and were then turned down to size. Specimen 7 was accidentally broken and was not available for testing magnetically. The magnetisation and permeability curves for all the

specimens are given in Fig. 2, and the magnetic properties are shown in Table II.

TABLE II.

Specimen.	B _{max.} (Max. Magnetic Induction).	H _{max.} (Max. Magnetic Field Strength).	μ _{max.} (Max. Permeability).	H for μ _{max.}	Remanent Magnetism.
1	9,977	99.58	264.0	15.1	5025
2	9,678	99.78	237.0	16.2	4733
3	11,480	98.9	481.5	8.0	5124
4	11,644	100.13	497.0	8.0	5523
5	11,747	100.53	549.0	6.9	4578
6	11,900	100.3	737.0	7.8	4724
8	11,090	101.43	271.6	16.0	4667
9	10,833	101.43	253.0	16.0	4431
10	10,540	98.36	254.0	14.0	4060

The most prominent feature is the magnetic superiority of the annealed bars compared with the unannealed specimens. The way in which the curves leave the origin is particularly noticeable. The curves of the cast specimens leave the origin at an angle of 45°, whereas the angle between the horizontal axis and the curves of the annealed bars is very much greater. The effect of annealing may be seen by comparing specimens 6 and 8, which have almost identical silicon contents. Specimen 6 has been annealed before turning, but specimen 8 is in the cast condition. The maximum induction of the former is 11,900 C.G.S., whilst that of the latter is 11,090 C.G.S.

The maximum induction is increased by increasing the silicon content, as shown in Fig. 3.

The dotted curves in Fig. 2 represent the change of permeability with respect to the field, and it will be noticed that the maximum permeability increases with increasing silicon content, and that the maximum permeability of the annealed specimens is more than twice that of the unannealed ones. The low induction of specimen 2 is due to the high percentage of combined carbon. The magnetic properties of the cast specimens appear to deteriorate the higher the content of silicon. Thus, specimen 10 is not as good magnetically as specimen 9, which in its turn is not as good as specimen 8. However, silicon does have a beneficial effect in the cast condition,

since specimens 8, 9, and 10 have higher inductions than either specimens 1 or 2.

For the purpose of annealing, all the bars were embedded in their own turnings in a sealed iron box. They were then heated to 875° C. and allowed to cool at the slow rate of 30° C. per hour to

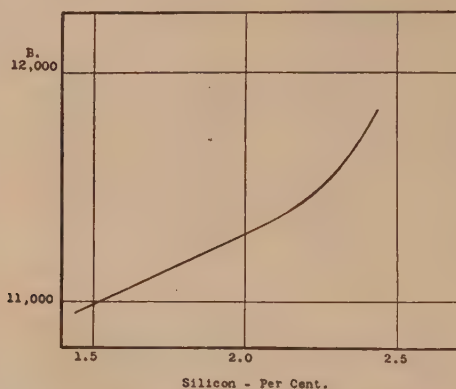


FIG. 3.—Influence of Silicon on the Induction.

675° C., from which point they were allowed to cool with the muffle. In this way most of the carbon was precipitated as finely divided graphite, the strains due to turning were removed, whilst oxidation was prevented by annealing the specimens in their own turnings. Primary magnetisation curves were again taken and the maximum inductions are given in Table III.

TABLE III.

Specimen.	$B_{\max.}$	$H_{\max.}$
1	10,170	99.45
2	9,810	100.0
3	11,060	98.35
4	11,320	101.4
5	11,480	99.1
6	11,430	99.2
8	11,690	100.5
9	11,570	103.8
10	11,960	99.8

Thus the magnetic induction of the annealed specimens increases with increasing silicon content. The magnetic properties of the samples were determined by taking hysteresis loops. These loops are not produced here but are available if required. The results of the tests are summarised in Table IV.

TABLE IV.

Specimen.	Coercive Force.	Hysteresis Loss in ergs/c.c. per Cycle, for B = 10,000.	Watts Loss per Lb. of Metal.
2	12·7	34,080	20·08
3	9·8	27,680	15·73
4	8·5	26,120	15·40
5	7·0	23,860	14·09
6	6·5	18,850	11·21
9	7·6	20,120	11·86
10	3·5	8,700	5·15

It will be noticed that, with the exception of specimen 9, the addition of silicon reduces both the hysteresis loss and the coercive force. Moreover, with high silicon content, as in specimen 10, the hysteresis loss is exceptionally low, being nearly as low as that of wrought iron. The last column in the table gives the energy dissipated per lb. of iron, assuming the specimen to be subjected to 100 magnetic cycles per second at a flux density of 10,000 maxwells, and that the density of the specimen is 7·7.

It was then decided to investigate fully the effect of silicon. Accordingly, bars were cast containing up to 8 per cent. of this element, turned to a diameter of about 1·170 centimetre, and then ground to a diameter of 1·128 centimetre. The analysis of these specimens is given in Table V.

TABLE V.

Specimen.	Si.	T.C.	C.C.	G.C.	Mn.
11	2·54	3·06	1·35	1·71	0·02
12	2·87	2·97	1·25	1·72	0·03
13	3·41	2·97	1·17	1·80	0·032
14	4·76	2·76	0·88	1·88	0·053
15	6·04	2·61	0·09	2·52	0·085
16	7·38	2·4	0·1	2·3	0·095

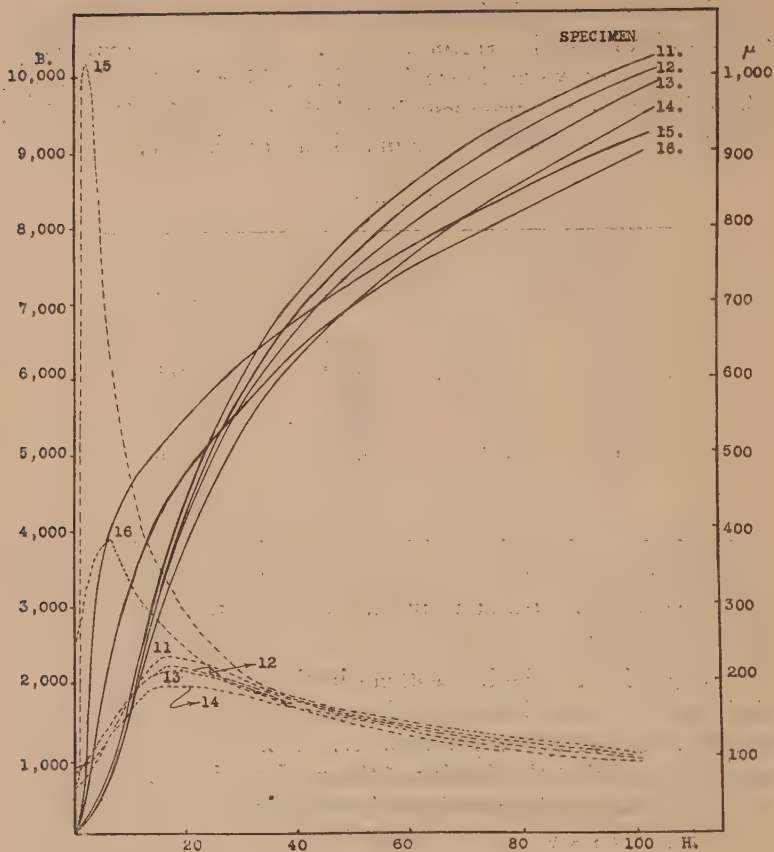


FIG. 4.

TABLE VI.

Specimen.	$B_{\max.}$	$H_{\max.}$	$\mu_{\max.}$	H for $\mu_{\max.}$	Remanence.
11	10,190	99.75	230	16.4	4300
12	10,100	100.13	218	16.4	4290
13	9,845	100.2	213	15.2	3800
14	9,455	100.13	193	20.48	2900
15	9,200	99.71	1021	2.25	2900
16	8,935	97.3	383	5.88	1650

Primary magnetisation and permeability curves were taken by using the permeameter and are shown in Fig. 4. A summary of the magnetic properties is given in Table VI.

Thus silicon decreases the magnetic induction and the remanence, and, when present in amounts not exceeding 5 per cent., it also decreases the maximum permeability. On referring to Fig. 4 it will be noticed that the inductions of specimens 15 and 16 are very much greater than the inductions of the other specimens in comparatively weak fields (up to about 25 gauss). This property is reflected in the permeability curves, the permeability of specimen 15 being 1021 C.G.S. at a force of only 2.25 C.G.S.

Hysteresis loops were next determined, and the magnetic properties are given in Table VII. Owing to the magnetic hardness of some of the specimens, the hysteresis loops could not be determined between the limits of $B = 10,000$ maxwells. The limits of induction between which the loop was determined are given in the first column of Table VII. However, it must not be supposed that the hysteresis loss is directly proportional to the limits of induction between which the loop is determined, since the loop becomes very narrow at its extremities.

TABLE VII.

Specimen.	Limits of Induction.	Coercive Force.	Hysteresis Loss ergs/c.c. per cycle.	Watts Loss per lb.
11	10,000	12.7	32,435	19.10
12	10,000	13.1	32,900	19.42
13	10,000	12.0	28,700	16.90
14	10,000	9.8	22,840	13.45
15	8,000	2.2	4,675	2.40
15	4,500	1.7	2,390	1.40
16		Accidentally broken		

Thus, with the exception of specimen 11, silicon reduced the coercive force and the hysteresis loss. The hysteresis loss of specimen 15 is exceptionally low, and it is remarkable in that it occurs in an alloy which is in the cast state.

The Effect of Manganese.—In order to investigate the effect of manganese on the magnetic properties of cast iron, the manganese was varied whilst the silicon was kept constant.

The analysis of these specimens is given in Table VIII.

TABLE VIII.

Specimen.	Mn.	Sl.	T.C.	C.C.	G.C.
M1	0.235	1.724	2.64	1.35	1.29
M2	0.63	1.736	2.82	1.38	1.44
M3	1.07	1.727	2.69	1.49	1.2
M4	1.49	1.705	2.73	1.41	1.32
M5	2.66	1.466	2.65	2.65	nil

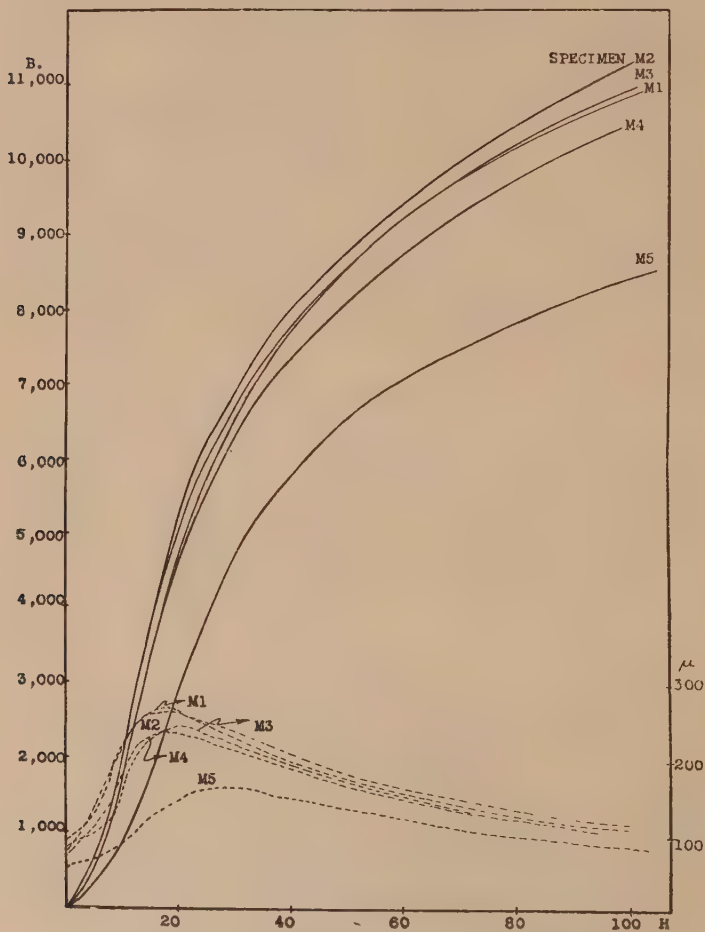


FIG. 5.

The magnetisation and permeability curves are given in Fig. 5, and the magnetic properties are given in Table IX.

TABLE IX.

Specimen.	$B_{\max.}$	$H_{\max.}$	$\mu_{\max.}$	H for $\mu_{\max.}$	Remanence.
M1	10,900	100·13	264	15	4950
M2	11,225	99·96	260	17·2	4960
M3	11,016	99·59	241·2	20·2	5420
M4	10,240	93·9	234	16·6	5090
M5	8,420	100	160	30	4600

Thus manganese is prejudicial to good magnetic properties and should be as low as possible when cast iron having high induc-

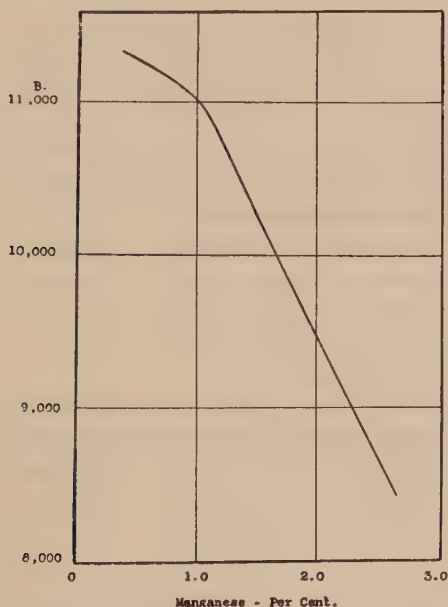


FIG. 6.—Effect of Manganese on the Induction.

tion and high permeability is required. Fig. 6 shows the deterioration of magnetic induction with increase of manganese content.

The low induction of specimen M1 is discussed in a later section.

All specimens, with the exception of M5, were then annealed at 875° C., surrounded by their own turnings in a closed iron box, and were allowed to cool very slowly. Magnetisation curves and hysteresis loops were determined; the magnetic properties are given in Table X.

TABLE X.

Specimen.	Max. Induction.	Remanent Magnetism.	Coercive Force.	Hysteresis Loss in ergs/c.c. per Cycle for B = 10,000.	Hysteresis Loss in Watts per Lb.
M1	11,160	5550	Accidentally broken		
M2	11,400	5930	9.5	28,200	16.6
M3	11,180	5800	11.0	29,550	17.82
M4	10,560	5440	12.0	31,600	18.61
M5 *	8,520	4760	20.0	35,000	20.62

* Between the limits of 7600 maxwells.

Thus annealing raises the magnetic induction, the slight increase in this case being due to the removal of strain. In the annealed condition, as in the cast condition, manganese increases the hysteresis loss and the coercive force, but decreases the magnetic induction and remanent magnetism.

The remanent magnetism and coercive force of specimen M5 are very low compared with magnet steel. Since manganese tends to decrease the remanent magnetism, it may be concluded that the addition of this element to cast iron will not produce a material suitable for permanent magnets.

The Effect of Aluminium.—Aluminium was added to American washed iron in order to find its effect on the magnetic properties of cast iron. The analysis of the specimens is given in Table XI.

TABLE XI.

Specimen.	Al.	Mn.	Si.	T.C.	C.C.	G.C.
A1	0.31	trace	0.047	3.09	3.06	0.03
A2	0.62	"	0.047	3.05	2.96	0.09
A3	1.03	"	0.046	2.84	1.34	1.50
A5	1.23	"	0.045	2.56	1.91	0.65
A6	3.00	"	0.046	2.60	1.42	1.18

Specimens A1, A2, and A3 were annealed at 900° C. for fifteen minutes. The magnetisation and permeability curves are given in Fig. 7, and a summary of the magnetic properties is given in Table XII.

TABLE XII.

Specimen.	$B_{\max.}$	$H_{\max.}$	$\mu_{\max.}$	H for $\mu_{\max.}$	Remanent Magnetism.
A1	10,530	100·13	319	13·2	5900
A2	10,310	99·15	289	15·0	5660
A3	9,980	99·59	245	18·0	4940
A5	8,780	99·25	125·5	42·75	3970
A6	7,950	101·03	105·2	38·5	4170

Thus there is a steady decrease in the maximum induction as the aluminium content is increased. The remanent magnetism also decreases as the percentage of aluminium increases.

The effect of annealing is very pronounced, the curves for specimens A5 and A6 being very much lower than those of the annealed specimens.

Before taking hysteresis loops, the specimens were annealed in their own turnings at 875° C. and allowed to cool very slowly. Primary magnetisation curves and hysteresis loops were then determined. A summary of the magnetic properties is given in Table XIII.

TABLE XIII.

Specimen.	$B_{\max.}$	$H_{\max.}$	Remanence.	$\mu_{\max.}$
A1	10,700	102·7	6210	360
A2	10,540	101·1	5990	321
A3	10,370	100·13	5760	312
A5	13,470	99·4	4800	1045
A6	12,850	100·7	4600	1030

Thus up to 1 per cent. aluminium causes a slight decrease in the induction, but the most noticeable feature is the extremely high induction of specimens A5 and A6. In the cast condition the inductions of these specimens were 8776 and 7950 respectively, whereas in the annealed condition they are 13,470 and 12,850 respectively. Moreover, the permeability of these specimens has

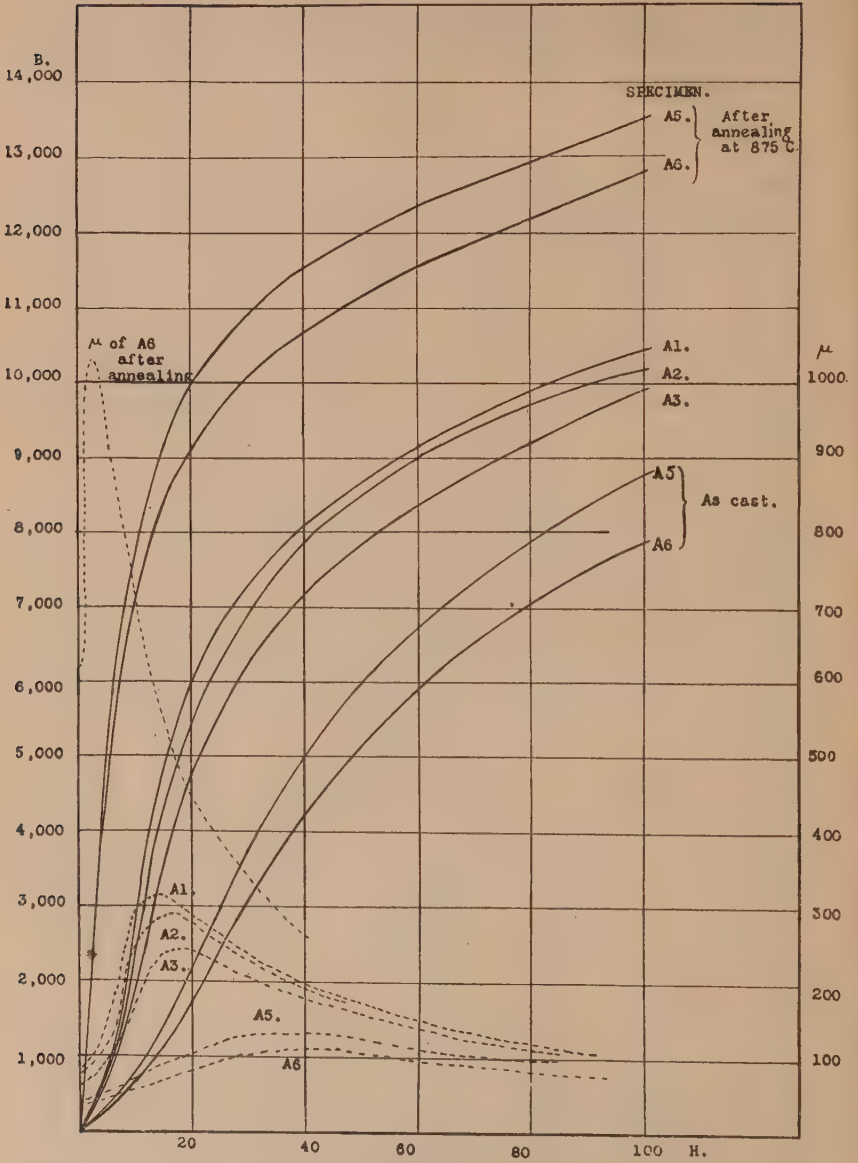


FIG. 7.

been increased tenfold by annealing, as shown in Table XIV., which also gives the graphite analyses of the specimens before and after annealing.

TABLE XIV.

Specimen.	Cast Condition.			Annealed.		
	$\mu_{\max.}$	H for $\mu_{\max.}$	Graphite.	$\mu_{\max.}$	H for $\mu_{\max.}$	Graphite.
A5	125.5	42.75	0.65	1045	2.5	2.1
A6	105.2	38.5	1.18	1030	3.0	2.45

The magnetisation and permeability curves for specimens A5 and A6 in the annealed condition are shown in Fig. 7. The extremely high induction of these specimens is largely due to the small amount of combined carbon, and to the distribution of the graphite. Table XV. gives a summary of the properties of these specimens.

TABLE XV.

Specimen.	Coercive Force.	Hysteresis Loss in ergs/c.c. per Cycle for B = 10,000.	Loss in Watts per Lb. of Metal.
A1	9.9	28,000	16.50
A2	13.0	36,210	21.34
A3	12.4	36,100	21.26
A5	3.4	9,000	5.30
A6	2.7	7,100	4.17

Thus aluminium, up to 1 per cent., apparently increases both the coercive force and the hysteresis loss, but further addition causes a huge decrease. The coercive force and hysteresis loss of specimens A5 and A6 are very little greater than those of wrought iron.

In order to investigate in detail the effect of aluminium on the magnetic properties of cast iron, it was decided to prepare alloys containing from 1 to 7 per cent., and from 18 to 24 per cent. of this element, *i.e.* to prepare only those alloys which can be machined. However, only about one-half of these specimens have been prepared up to the present, and the analysis of these is given in Table XVI.

TABLE XVI.

Specimen.	Al.	T.C.	C.C.	G.C.	Si.	Mn.
A7	0.865	3.61	1.35	2.26	0.03	trace
A9	1.52	3.63	1.48	2.15	0.03	"
A10	2.23	3.52	1.63	1.89	0.02	"
A11	2.50	3.64	1.34	2.30	0.023	"
A12	2.83	3.50	1.59	1.91	0.025	"
A13	3.60	3.61	1.36	2.25	0.018	"
A14	4.09	3.42	1.57	1.85	0.02	"

The primary magnetisation and permeability curves are given in Fig. 8, and a summary of the magnetic properties is given in Table XVII.

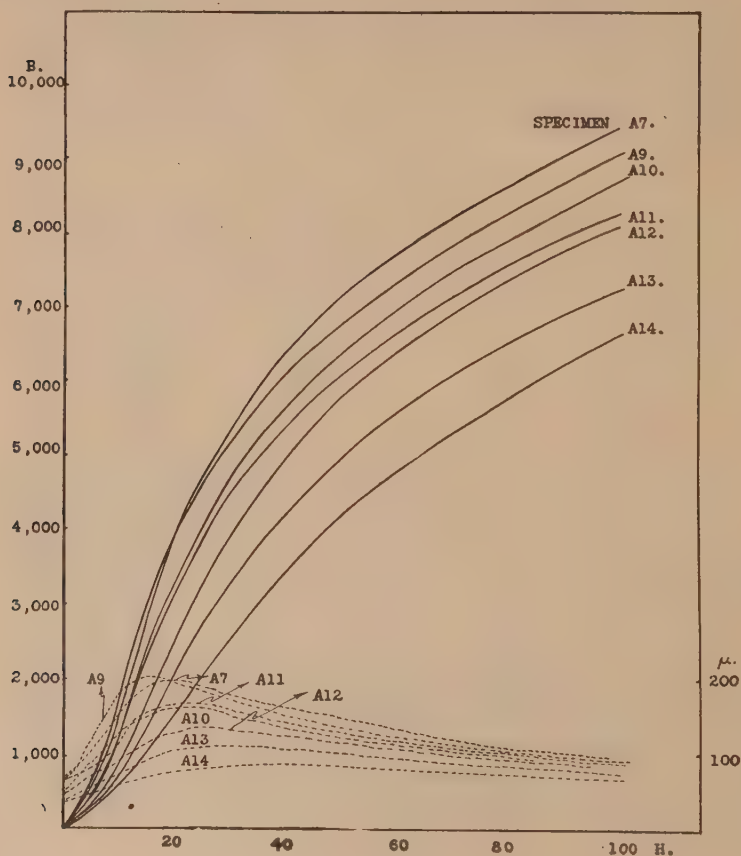


FIG. 8.

TABLE XVII.

Specimen.	$B_{\max.}$	$H_{\max.}$	$\mu_{\max.}$	H for $\mu_{\max.}$	Remanence.
A7	9450	98·35	196	19·88	3850
A9	9155	100·13	199	16·20	3850
A10	8750	98·35	165	20·56	3586
A11	8440	104·80	158	18·12	3500
A12	8140	93·70	134	26·0	3040
A13	7260	98·31	109	32·36	3410
A14	6660	98·33	87	41·30	3210

Thus aluminium decreases the maximum induction, the maximum permeability, and the remanent magnetism. The magnetic properties obtained from the hysteresis loops are given in Table XVIII.

TABLE XVIII.

Specimen.	Limits of Induction between which the Loop was determined.	Coercive Force.	Hysteresis Loss in ergs/c.c. per Cycle.	Loss in Watts per Lb. of Metal.
A7	9600	13·4	31,750	18·70
A9	9100	12·7	30,335	17·87
A10	8800	14·4	30,810	18·15
A11	8500	14·8	31,880	18·78
A12	8100	18·4	39,790	23·44
A14	6700	24·6	41,540	24·47

Except in the case of specimen A7, aluminium increased the coercive force and increased the hysteresis loss.

The Effect of Chromium.—Chromium in the form of 62 per cent. ferro-chrome was added to American washed iron, to which sufficient 45 per cent. ferro-silicon had been added to raise the silicon content to 1·7 per cent. The specimens had to be prepared in two heats. The three bars containing the larger amounts of chromium were satisfactory, but the specimens containing the smaller amounts of this element were high in silicon. The analysis of the specimens is given in Table XIX., and the magnetisation and permeability curves are shown in Fig. 9.

TABLE XIX.

Specimen.	Si.	Cr.	Mn.	T.C.	C.C.	G.C.
C1	2.632	0.63	0.02	2.59	1.21	1.38
C2	3.627	1.06	trace	2.42	0.94	1.48
C3	3.116	1.79	0.015	2.45	1.06	1.39
C6	1.71	7.51	0.01	2.10	2.10	nil

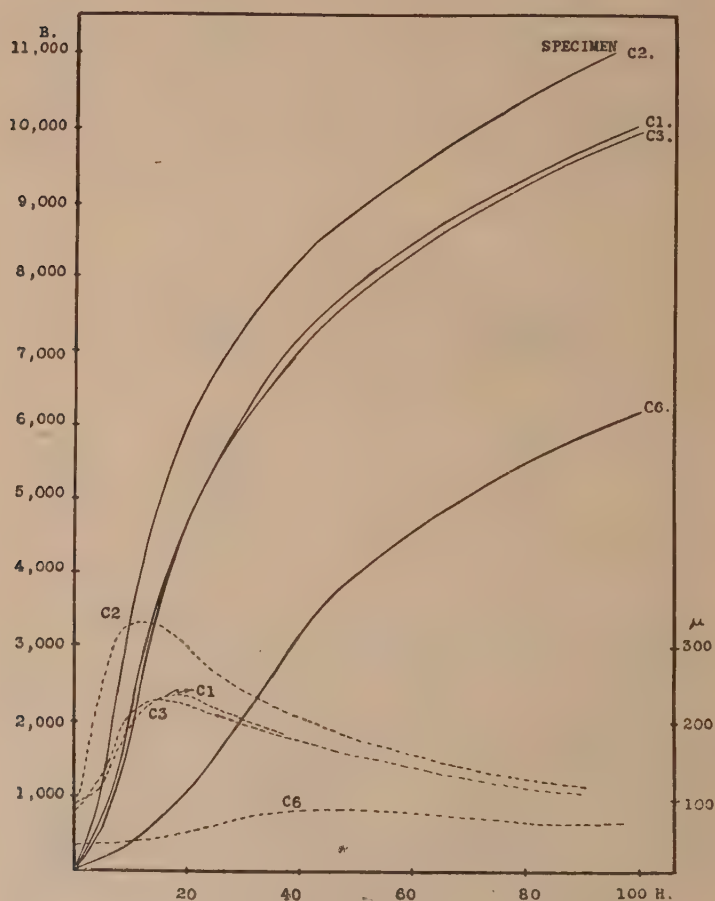


FIG. 9.

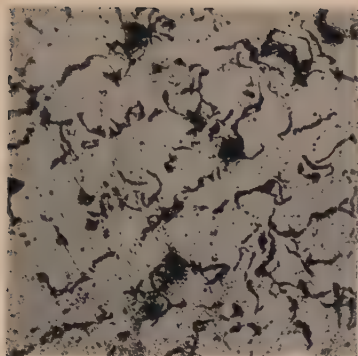


FIG. 15.—Specimen 5. Etched.
× 100.

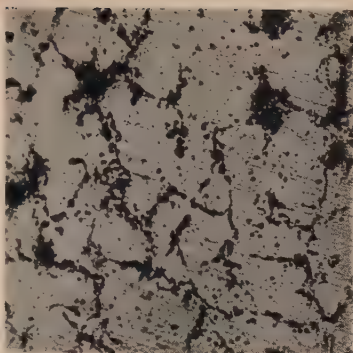


FIG. 16.—Specimen 6. Etched.
× 100.



FIG. 17.—Specimen 8. Etched.
× 100.

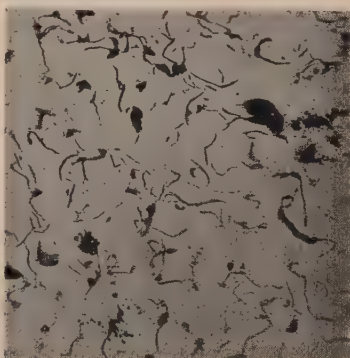


FIG. 18.—Specimen 10. Unetched.
× 100.

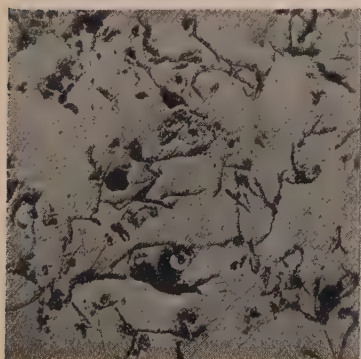


FIG. 19.—Specimen M1. Unetched.
× 100.



FIG. 20.—Specimen M2. Etched.
× 100.

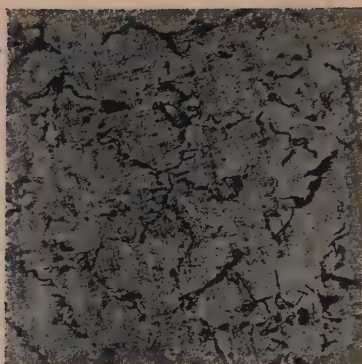


FIG. 21.—Specimen M3. Etched.
×100.



FIG. 22.—Specimen M5. Etched.
×100.

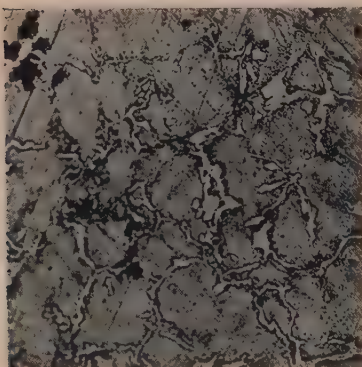


FIG. 23.—Specimen A5. Etched.
×100.

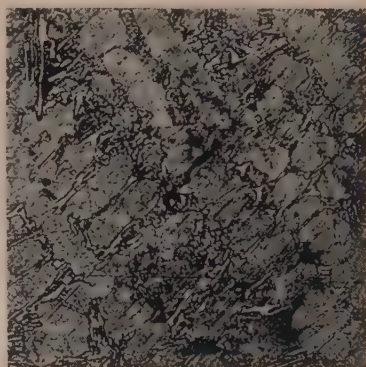


FIG. 24.—Specimen C6. Etched.
×100.

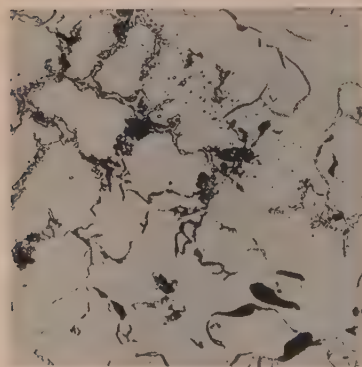


FIG. 25.—Specimen N3. Etched.
×100.

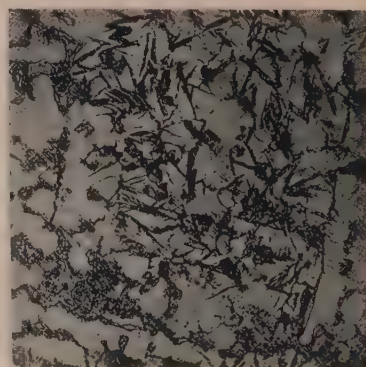


FIG. 26.—Specimen F. Etched.
×100.

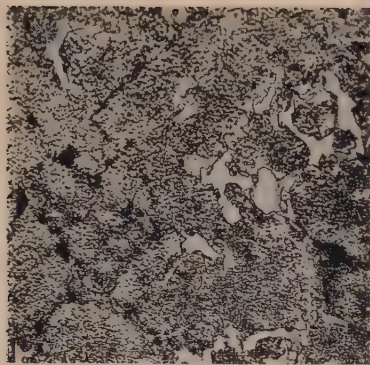


FIG. 27.—Specimen N3. Etched.
×100

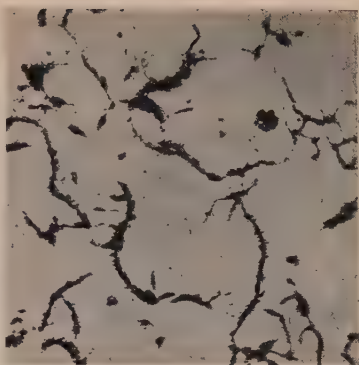


FIG. 28.—Specimen 4. Unetched.
×100.

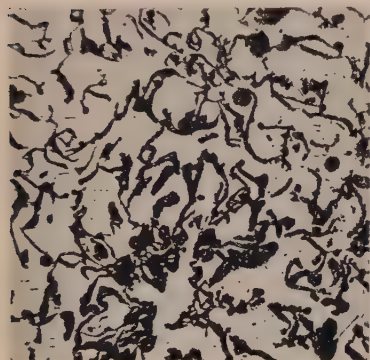


FIG. 29.—Specimen 10. Unetched.
×100.

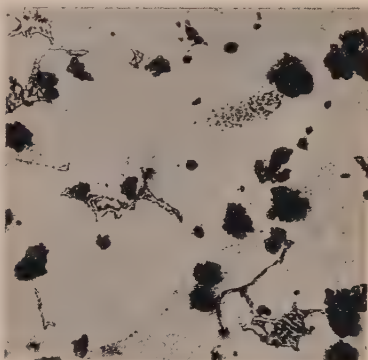


FIG. 30.—Specimen A5. Etched.
×100.

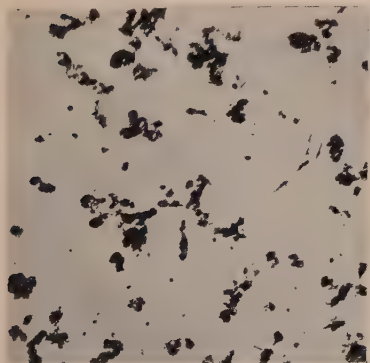


FIG. 31.—Specimen A6. Unetched.
×100.

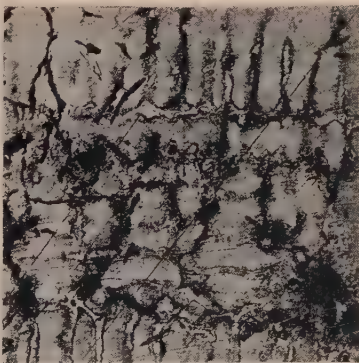


FIG. 32.—Specimen A14. Etched.
×100.

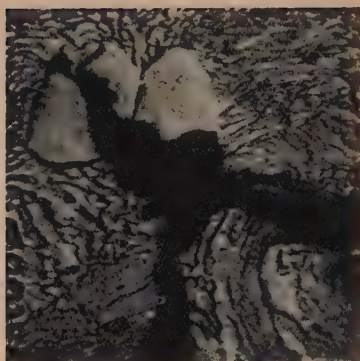


FIG. 33.—Specimen A14. Etched.
×1000.

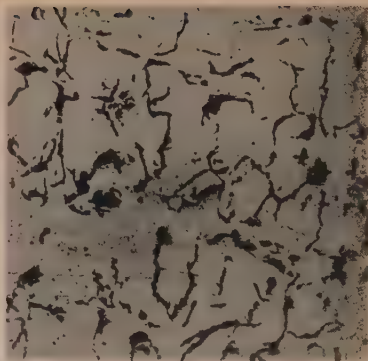


FIG. 34.—Specimen Co1. Unetched.
×100.

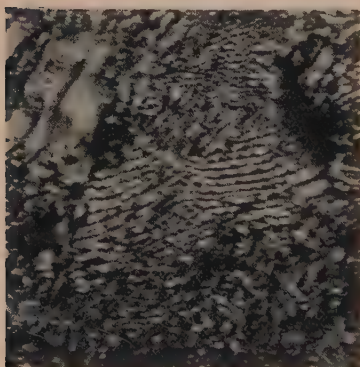


FIG. 35.—Specimen Co2. Etched.
×1000.

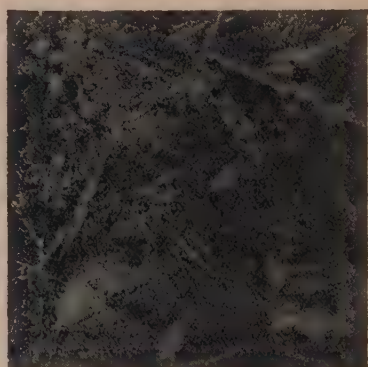


FIG. 36.—Specimen Co2. Etched.
×300.

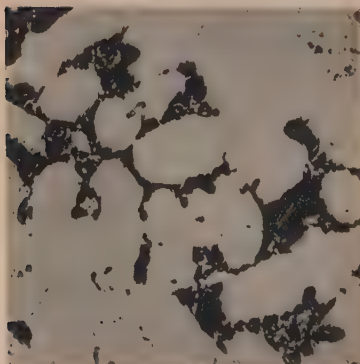


FIG. 37.—Specimen Co4. Unetched.
×100.

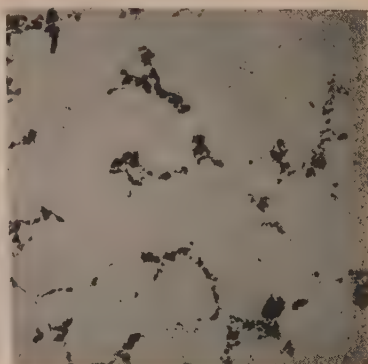


FIG. 38.—Specimen Co5. Unetched.
×100.

A summary of the chief magnetic properties is given in Table XX.

TABLE XX.

Specimen.	B _{max} .	H _{max} .	μ _{max} .	H for μ _{max} .	Remanent Magnetism.
C1	9,925	97·43	231	15·1	4460
C2	10,970	96·58	330	13·1	5150
C3	9,920	99·07	229·7	17·4	4160
C6	6,120	99·6	80	45	3310

Thus chromium is prejudicial to good magnetic properties, since specimen C6 has a maximum induction of only 6120 C.G.S. It is difficult to draw accurate conclusions from specimens C1, C2, and C3, owing to the varying amounts of silicon. The induction of specimen C2 is high owing to the large percentage of silicon, whilst the induction of specimen C3 is not very much less than that of specimen C1, because the former contains $\frac{1}{2}$ per cent. more silicon than the latter. The addition of chromium decreases the maximum permeability and the remanent magnetism, and increases the force at which this maximum permeability occurs.

Specimens C1, C2, and C3 were embedded in their own turnings in a closed iron box, annealed at 875° C. and allowed to cool very slowly. Primary magnetisation curves and hysteresis loops were determined. The magnetic properties are given in Table XXI.

TABLE XXI.

Specimen.	Remanent Magnetism.	Coercive Force.	Hysteresis Loss in ergs/c.c. per Cycle for B = 10,000.	Hysteresis Loss in Watts per Lb. of Metal.
C1	5550	11·8	31,130	18·70
C2	5290	10·0	29,000	17·14
C3	4960	8·7	24,000	14·15
C6	3350	33·0	45,350	26·75

Thus chromium appears to decrease the remanent magnetism, and to increase the coercive force and hysteresis loss. Specimen C6 was not annealed in order to obtain an idea of its utility as a permanent magnet. The coercive force is fairly high, but the remanent magnetism is very low, and hence the product is only in

the neighbourhood of 110,500. Apparently chromium is capable of giving a sufficiently high coercive force, but only at the expense of the remanent magnetism, which would be reduced to a very small amount.

The Effect of Phosphorus.—In order to determine the effect of this element, silicon and phosphorus were added to American washed iron. The analysis is given below :

	T.C.	C.C.	G.C.	Si.	P.	Mn.
Specimen P . . .	2.64	1.53	1.01	1.67	1.86	0.02

This specimen had a maximum induction of 10,970 C.G.S. and a maximum permeability of 265 at a force of 15.75 gauss.

Unfortunately, this specimen cannot be compared with an unannealed bar of identical analysis, but it will be seen that specimen 8, containing 2.4 per cent. of silicon, has a maximum induction of 11,090 C.G.S., whereas specimen P, which contains 1.67 per cent. of silicon, has a maximum induction of 10,970 C.G.S. Thus the effect of phosphorus is not very great, and it probably tends to increase the induction.

Non-Magnetic Alloys.—Two specimens of the following analysis were prepared :

Specimen.	Ni.	Si.	Mn.	T.C.	C.C.	G.C.	P.
N3	12.35	1.30	0.025	2.56	1.16	1.4	...
F	10.00	2.57	2.04	2.20	0.59	1.61	1.96

The primary magnetisation and permeability curves are given in Figs. 10 and 11 respectively, from which it will be seen that the specimens are very feebly magnetic.

Table XXII. gives the chief magnetic properties of these specimens.

TABLE XXII.

Specimen.	B _{max.}	H _{max.}	μ _{max.}	H for μ _{max.}	Remanent Magnetism.
N3 (as cast)	419	99.15	4.6	60	6
F " "	377	99.61	3.8	60	nil
N3 {annealed }	3140	103.2	35.0	57	1330
F {at 875° C. }	3280	105.5	33.7	46	1630

The non-magnetic property of these specimens in the cast condition is due to the fact that the specimen remains in the austenitic condition, and the specimens become magnetic on annealing owing to the formation of martensite.

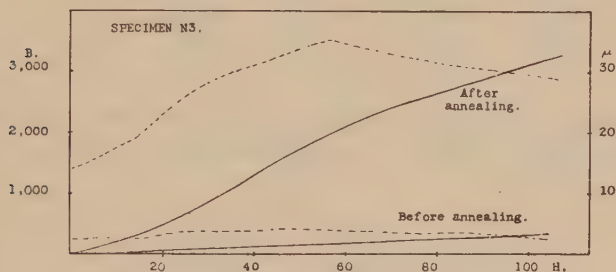


FIG. 10.

The Effect of Cobalt.—Cobalt, in the form of metallic cubes, was added to American washed iron in order to determine the effect of this element on the magnetic properties of cast iron. From the results of a preliminary experiment, it appeared that cobalt would

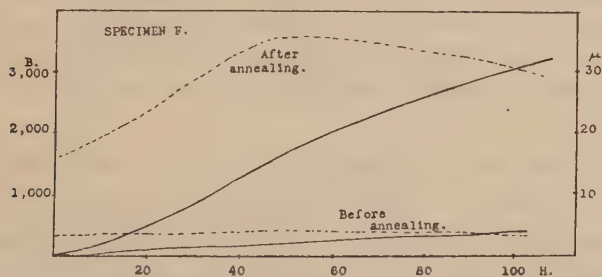


FIG. 11.

make the iron sound and precipitate sufficient graphite to render the iron machinable. However, this was not the case, and so the bars were remelted and silicon was added. The analysis of the specimens is given in Table XXIII.

TABLE XXIII.

Specimen.	Co.	Si.	T.C.	C.C.	G.C.	Mn.
Co1	1.86	2.18	2.76	1.28	1.48	0.045
Co2	6.51	0.905	2.91	1.57	1.34	0.02
Co4	19.9	0.66	2.36	1.28	1.11	0.01
Co5	23.33	0.65	2.20	0.83	1.37	0.01

Primary magnetisation and permeability curves are shown in Fig. 12, whilst a summary of the magnetic properties is given in Table XXIV.

TABLE XXIV.

Specimen.	$B_{\max.}$	$H_{\max.}$	$\mu_{\max.}$	H for $\mu_{\max.}$	Remanence.
Co1	10,600	97.0	231	16.2	4700
Co2	10,340	98.35	206	20.3	5240
Co4	13,095	102.0	266	20.0	6000
Co5	13,440	96.92	286	21.3	6100

Thus cobalt increases the magnetic induction, remanent magnetism, and the maximum permeability. The induction of specimen Co1 is as high as that of specimen Co2, because the former contains more graphitic carbon and less combined carbon than the latter. This is undoubtedly due to the presence of the 2.18 per cent. of silicon which this specimen contains.

THE RELATION BETWEEN THE MAGNETIC PROPERTIES AND THE STRUCTURE.

Microscopical examination of the specimens was carried out, and from this it would appear that the magnetic properties depend to a great extent on the microstructure. Specimens 5 and 6 were annealed at 900° C. for fifteen minutes, and the graphite exists in the form of temper carbon and as small curly flakes around the ferrite grains, as shown in micros Figs. 15, 16. Some pearlite grains are also seen. The graphite exists in flakes in specimen 8 (Fig. 17), whilst the background is pearlite. The distribution of graphite in specimen 10 is shown in the unetched photomicrograph Fig. 18 (Plate XVIII.).

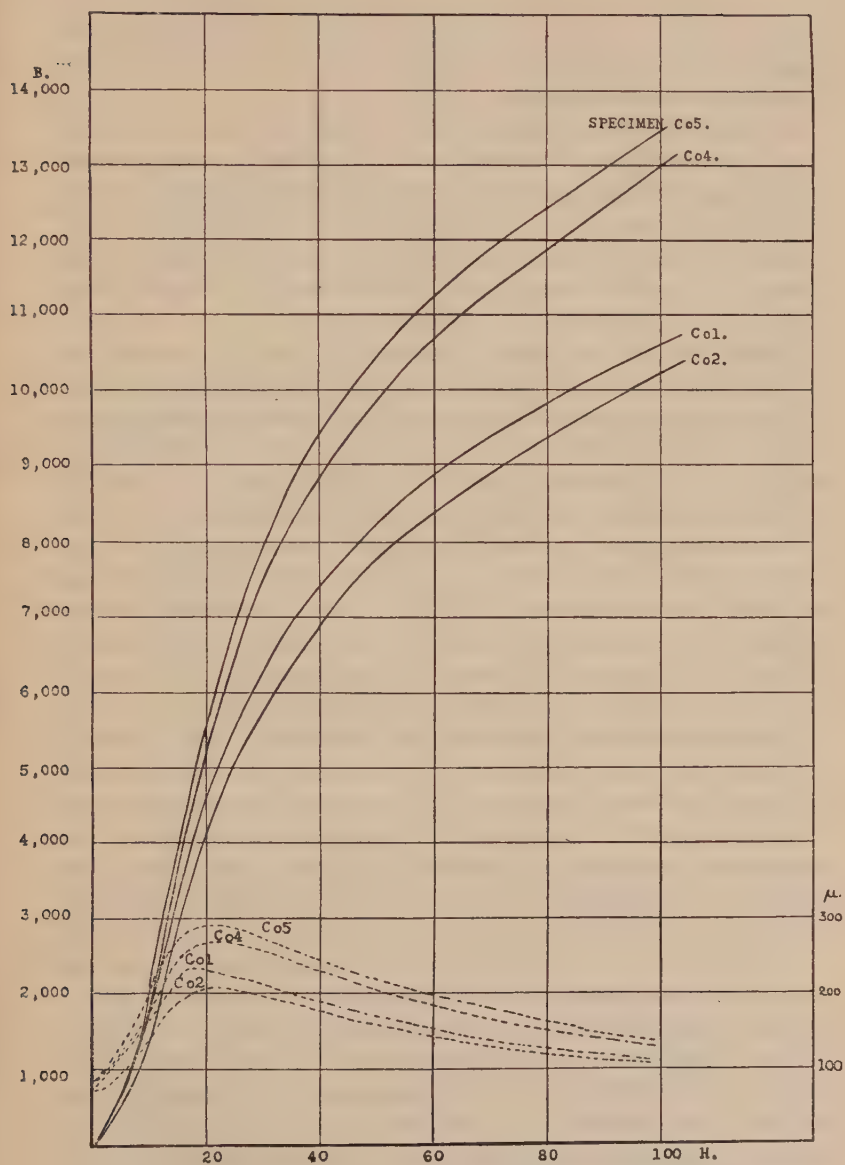


FIG. 12.

Thus for the highest magnetic induction and permeability, the graphite should exist as temper carbon, and as much ferrite as possible must be present. Graphite in the form of flakes is not favourable to high induction.

The structure of specimens M1, M2, M3, and M5 is shown in Figs. 19 to 22 (Plates XVIII. and XIX.). The flakes of graphite in specimen M1 are rather large, and this accounts for its inferior magnetic properties and its high electrical resistance. The graphite is more in the nodular form in specimen M2 than in specimen M3, which contains some free cementite. Fig. 22 shows the double carbide of iron and manganese.

From micros, Figs. 23, 24, it is seen that there is a network of free cementite round the pearlite grains in specimens A5 and C6.

Thus the presence of free carbide denotes low magnetic induction, and should be avoided at all costs when high permeability is required. The presence of carbide also indicates high coercive force, high hysteresis loss, and low remanent magnetism.

The structure of specimen N3 is shown in micro Fig. 25, from which it will be noticed that the graphite exists in flakes in an austenitic ground-mass, and that there is a small amount of free carbide of iron and nickel present. Thus nickel causes the iron to remain in the austenitic condition after cooling in the mould, and consequently the specimen is non-magnetic.

Micro Fig. 26 shows the structure of specimen F, which is mainly austenitic, but also contains a little martensite, as well as an intergranular constituent consisting of a mixture of cementite and phosphide eutectic, and graphite. In this case the nickel and manganese produced an austenitic structure, and hence this specimen is non-magnetic. The presence of martensite made the iron extremely hard and difficult to machine.

On annealing at 875°C. , specimens N3 and F became martensitic, and consequently became magnetic. The structure of specimen N3 is shown in micro Fig. 27 (Plate XX.).

The structures of the annealed specimens 4, 10, A5, and A6 are shown in micros Figs. 28 to 31 respectively. The high induction and low hysteresis loss of these specimens is due to the large amount of ferrite and the presence of all the carbon in the nodular form as temper carbon.

The structure of specimen A14 is shown in micros Figs. 32, 33

(Plates XX. and XXI.). It consists of pearlite, free cementite, and graphite, hence its low induction.

The structure of the specimens containing cobalt is shown in micros Figs. 34 to 38 (Plate XXI.). Fig. 34 shows the distribution of graphite in specimen Co1. Owing to the relatively small amount of cobalt present (2 per cent.), and also to the high silicon content of this iron, the graphite is in flakes, whereas in specimens Co2, Co4, and Co5 it is in the nodular form, as seen from Figs. 37 and 38. The matrix of all the specimens containing cobalt is pearlite, as shown in Fig. 35.

Moreover, free cementite is present in specimens Co1 and Co2, as shown in Fig. 36. A moderate amount of eutectic, which has a higher ratio of cementite to austenite than usual, is also present in specimens Co1 and Co2, but is absent in specimens Co4 and Co5. Until further microscopical investigation has been carried out, it is difficult to state whether the relatively high induction of these specimens is due to the inherent magnetic properties of cobalt carbide, or to the continuity of the mass, due to the graphite being present in the nodular form.

The Electrical Conductivity.—The specific resistance of the specimens was measured by passing a small current and measuring the potential drop between two points on the specimen. In order to get accurate results the current was reversed and the specific resistance was determined for at least two different current strengths.

All specimens were in the cast condition, with the exception of those marked *, which were annealed at 900°C . for fifteen minutes before turning—*i.e.* all specimens were tested before they were embedded in their own turnings in a closed iron box and annealed at 875°C . for fifteen minutes. The specific resistances of the specimens are given in Table XXV.

One at once notices that there is a regular increase in the specific resistance of specimens 1 to 10, *i.e.* silicon increases the specific resistance. Moreover, annealing reduces the specific resistance, as shown in Fig. 13. Thus specimens 2 and 8 have greater resistivity than specimens 3 and 6 respectively, although the former contain less silicon than the latter. This is due to the fact that in the cast specimens the graphite exists in the form of flakes, which so cut up the mass of the iron that the passage

of the current is very much hindered, *i.e.* the resistance is very great. In the annealed specimens, however, the graphite exists in the form of temper carbon, and the continuity of the current is not affected to the same extent.

TABLE XXV.

Specimen.	Percentage of Element.	Specific Resistance. Microhms.
1	0.6	46.8
2	0.807	50.66
*3	1.43	47.73
*4	1.97	57.15
*5	2.26	60.95
*6	2.46	61.59
8	2.41	74.35
9	2.745	85.41
10	4.165	111.5
Silicon		
*A1	0.31	38.47
*A2	0.62	47.44
*A3	1.03	88.47
A5	1.23	69.56
A6	3.0	89.76
Aluminium		
M1	0.235	61.94
M2	0.63	59.36
M3	1.07	59.40
M4	1.49	64.95
M5	2.26	66.5
Manganese		
N3	12.35	115.9
Nickel		
F	10.00	101.4
	2.04	
Manganese		
P	1.86	88.7
Phosphorus		
C1	0.63	90.63
C2	1.06	...
C3	1.79	113.5
C6	7.51	64.6
Chromium		

Referring to the effect of aluminium (specimens A1 to A6), it will be seen that this element raises the specific resistance of cast iron. Thus the resistance of specimen A3 is greater than that of A2, which in its turn is greater than that of A1. Annealing lowers the resistance, due to deposition of graphite, as is evident from the fact that the resistance of specimen A5 is less than that of specimen

A3, whilst specimen A6 has only slightly higher resistance than A3, although specimens A5 and A6 contain more aluminium than

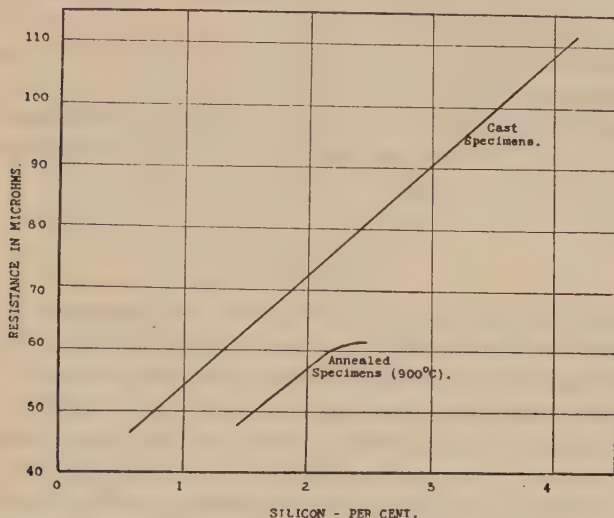


Fig. 13.—Influence of Silicon on the Electrical Conductivity.

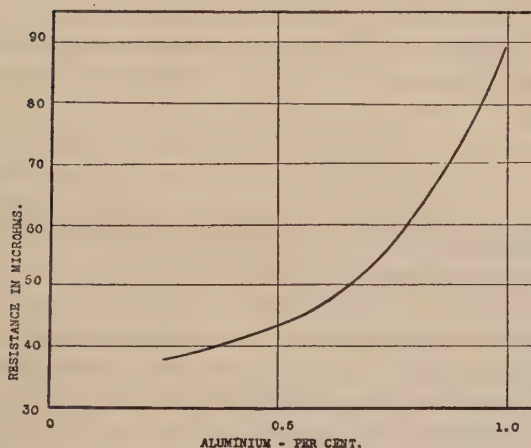


Fig. 14.—Influence of Aluminium on the Electrical Conductivity.

A3. The increase in resistance due to aluminium is shown graphically in Fig. 14.

With the exception of specimen M1, manganese increases the specific resistance of cast iron. The irregularity of specimen M1 was discussed in the section dealing with the relation of the magnetic properties to the structure.

It will be noticed that the resistances of specimens N3 and F are exceptionally high.

Phosphorus apparently increases the specific resistance, since specimen P has a specific resistance of 88.7 microhms/c.c., whereas specimen 8 has a resistance of only 74.35 microhms/c.c.

CONCLUSIONS.

1. The highest magnetic induction and permeability are obtained with cast iron which has been annealed. In the extreme case the magnetic induction was increased 70 per cent. and the maximum permeability was increased tenfold on annealing.

2. When high permeability is required, the graphite should be in the form of temper carbon, as little combined carbon as possible should be present, and free cementite must be absent.

3. In the cast state, silicon decreases the magnetic induction, but its presence may be advantageous in alloys which have to work at low flux densities (*e.g.* transformer cores). Specimen 15 is an example of an alloy which is very magnetic in comparatively weak fields, having a permeability of over 1000 C.G.S. at a field strength of 2.0 gauss.

4. Both in the cast and annealed conditions silicon reduces the coercive force and the hysteresis loss. In the case of specimens 10 and 15, the hysteresis losses are remarkably low, being equal to that of very soft iron. In the case of specimen 15, the low hysteresis loss is remarkable, since it occurs in a cast alloy.

5. Both in the cast and annealed conditions manganese, nickel, and chromium are prejudicial to high magnetic induction.

6. In the annealed condition manganese and chromium increase the coercive force and hysteresis loss and decrease the remanent magnetism.

7. In the cast state aluminium decreases the magnetic induction, permeability, and remanent magnetism, and increases the coercive force and the hysteresis loss.

8. In the annealed condition aluminium, in amounts up to

1 per cent., decreases the magnetic induction and the maximum permeability, but increases the coercive force and hysteresis loss. When present in amounts from 1 to 3 per cent., however, aluminium causes a huge increase in the induction and permeability, specimens A5 and A6 having inductions of over 13,000 C.G.S. and permeabilities of over 1000 C.G.S. It also causes a huge decrease in the coercive force and hysteresis loss. The coercive force and hysteresis loss of specimens A5 and A6 are very little greater than those of soft iron.

9. Phosphorus has little effect on the magnetic properties of cast iron, probably tending to increase the magnetic induction in alloys containing silicon.

10. The presence of sufficient nickel, or nickel and manganese, makes cast iron non-magnetic. Sufficient of these elements must be added to render the iron entirely austenitic, the presence of martensite making the iron feebly magnetic, hard, and difficult to machine. An easily machinable non-magnetic cast iron could be made by having nickel and manganese present in such proportions that the combined effect of these two elements on the carbon is negligible. Sufficient silicon would then be added to precipitate just sufficient graphite to give the required strength, machining properties, surface, &c.

11. In the cast state cobalt increases the magnetic induction and remanent magnetism, and increases the maximum permeability. The specimen containing 23 per cent. of cobalt has an induction of 13,440 C.G.S., which is exceptionally high for cast iron in the cast state.

12. Both manganese and chromium are capable of giving a sufficiently high coercive force for a good permanent magnet, but in doing so they reduce the remanent magnetism to a very small amount.

13. Silicon, manganese, and aluminium raise the specific resistance of cast iron.

14. Cast iron has a very high specific resistance, and is suitable for resistance grids which have to pass heavy currents.

In conclusion, the author wishes to thank Professor Turner not only for indicating such an interesting subject, but also for his kind interest in the work and for his many valuable suggestions.

He also desires to thank Professor S. W. J. Smith for giving every facility for carrying out the magnetic determinations, and for his kind interest in the work, which has been carried out in the Metallurgical and Physical Laboratories of the University of Birmingham, with the assistance of a grant from the Department of Scientific and Industrial Research. The author is indebted to the staffs of the Laboratories, and to his fellow research workers, for help and encouragement. His thanks are also due to the British Cast Iron Research Association, and particularly to Mr. S. E. Dawson, Member of Council of that Association.

CORRESPONDENCE.

Mr. E. ADAMSON (Sheffield) wrote that the author had shown a great deal of patience in compiling the numerous results given in his paper, but it would probably have been better had he carried out his experiments with a pure hæmatite pig iron which could have been obtained in this country, instead of on American washed iron which was perfectly white in fracture, but, when varying percentages of silicon were added, did not give a result in carbon and silicon ratios comparable to that usually found in virgin grey pig iron.

It was only necessary to give one illustration to show his (Mr. Adamson's) meaning. Samples 6 and 8 in Table I. were of practically the same silicon contents, yet one contained combined carbon 0.28 per cent. and the other combined carbon 1.46 per cent.

The difference in result between those two samples as given in Table II. was most marked in regard to maximum permeability. It was generally understood that in steels the combined carbon was an index to maximum permeability, and the figures given in Table II. under that heading would appear to confirm that without taking note of the silicon contents of the samples. Under the circumstances it did not appear possible to draw any definite conclusions on the influence of silicon, which was constant in those two cases.

As a further illustration, Table XI. showed the influence of aluminium on the composition, but the results in Table XII. appeared to follow roughly the percentages of aluminium. In the following table of annealed bars, however, the position was reversed, and they approximately followed the combined carbon, as might be expected.

Again, under the section dealing with the influence of manganese, the actual variables were manganese and combined and graphitic carbon. In dealing with chromium the actual variables were chromium and combined and graphitic carbon.

The actual variables in dealing with the influence of nickel were nickel, silicon, manganese, combined carbon, graphitic carbon, and phosphorus; and in dealing with the influence of cobalt the actual variables were cobalt, silicon, combined carbon, and graphitic carbon.

Under such conditions with so many variables it seemed very difficult to draw any definite conclusions from any one set of bars in regard to the influence of any one element dealt with in each series.

Mr. J. FERDINAND KAYSER (Sheffield) wrote that, although the author had worked with interesting and potentially useful alloys, he had not discovered the latent properties which many of them possessed. That was primarily brought about by the fact that cast iron, and modifications of cast iron, did not give either uniform or useful results

when tested in the untreated, or in the annealed, condition. The data had unfortunately been presented in such a form that it was necessary to retabulate the results in order to get a comprehensive view of the work done, and one then observed that, when testing the samples for what might loosely be called their "permanent magnet properties," the author missed out the only true criterion of permanent magnet efficiency—*i.e.* the maximum available energy per cubic centimetre.

Some two years ago, he (Mr. Kayser) covered practically all the ground covered by the author, but also tested his samples after first subjecting them to a treatment suitable for breaking down the solid solutions present, followed by a hardening process. If the author had adopted some such treatment, he would have found that the cast irons containing chromium, and those containing cobalt, had properties which would enable them to take their places amongst the highest class of permanent magnet steels.

By the addition of chromium to cast iron it was possible to obtain a coercive force as high as 120 C.G.S. units. The remanence and maximum available energy were always very low. The addition of a sufficient quantity of cobalt alone would enable coercive forces of 200 to 250 to be obtained. It was, in fact, possible to express the relationship between coercive force and cobalt content by the formula:

$$H_c = H_o (1 + kC),$$

where H_o was the initial coercive force of a cobalt-free cast iron, k a constant, and C the cobalt percentage present.

The most economical results were obtained by the simultaneous addition of cobalt and chromium, by means of which it was possible to obtain an alloy containing approximately 9 per cent. of chromium and 9 per cent. of cobalt, giving a maximum available energy of 20,000 ergs per cubic centimetre and a coercive force of approximately 175. That alloy was already a proved economical product, and some hundreds of thousands of cast magnets had been manufactured. He (Mr. Kayser) had already had the pleasure of presenting a small sample of that material to the author, and hoped he would try it out in his own laboratory and endeavour to bring about a still further improvement in the production of alloyed cast iron permanent magnets.

MR. PARTRIDGE wrote in reply that he was pleased to receive a communication from Mr. Adamson, and wished to point out that as far as he was aware there was not any literature on the progressive effect of any one element on the magnetic properties of cast iron. It was therefore decided to determine the progressive effect of elements usually associated with special steels on the magnetic properties of cast iron. In that way commercially useful alloys might be discovered and developed. Consequently the carbon-silicon ratio varied considerably, as was intended. American washed iron was a purer basis than hæmatite. The effect of silicon and manganese could thus be

determined from 0 per cent. to some arbitrary upper limit, which would not be possible if hæmatite were used as a basis.

The difference in the permeabilities of samples 6 and 8 was solely due to graphitisation caused by annealing, as stated in the paper.

When silicon was added to a white cast iron, the effect was twofold :

- (a) The silicon dissolved in the ferrite, thereby decreasing its maximum induction, but increasing its maximum permeability.
- (b) The silicon caused some or all of the carbide (depending on the amount of silicon present, and the rate of cooling) to decompose, thus precipitating graphite.

Now the liberation of free ferrite tended to increase the permeability, but the gaps produced in the specimen by the graphite tended to decrease it; the size and distribution of the graphite were of the greatest importance.

If now all the specimens had received the same treatment, as in the second series of specimens containing silicon, any change in the magnetic properties must be due entirely to the presence of that silicon. In that case silicon was the only real variable, and any change in the ratio of combined to graphitic carbon was due to the presence of that silicon.

The above argument also held for the addition of aluminium and manganese. In the case of such elements as nickel, cobalt, chromium, and manganese, a constant amount of silicon had to be added in order to obtain a sound, machinable bar, and any variation in that silicon was accidental.

He did not claim to have investigated the effect of nickel, and was at present engaged on the task.

It had been a great pleasure to hear Mr. Kayser's views on the subject, and he was greatly indebted to him for his interest and for the magnet steel presented to him. Up to the present he had been chiefly concerned in obtaining cast irons possessing high permeability and low hysteresis loss. He hoped, however, to consider "the permanent magnet properties" of cast iron in the near future, and consequently he appreciated Mr. Kayser's communication. He regarded the maximum available energy per cubic centimetre (as advocated by Mr. Kayser about two years ago) as being a much truer criterion of permanent magnet efficiency than the product: remanent magnetism \times coercive force ($B_r \times H_c$). But even the former did not take, the permanency of the magnet into account. In order to illustrate that the accompanying diagram (Fig. A) showed ideal hysteresis loops for steels 1 and 2. If the demagnetisation factor of a particular magnet were represented by OP, then steel 1 would be much more suitable than steel 2. If, however, the dimension ratio were such that the demagnetisation were represented by OP', steel 1 would be useless, and steel 2 would be highly suitable. Thus it was the slope of the tangent to the

hysteresis loop which determined the permanency of a magnet. Mr. Partridge thought that it was probable that the figures quoted by

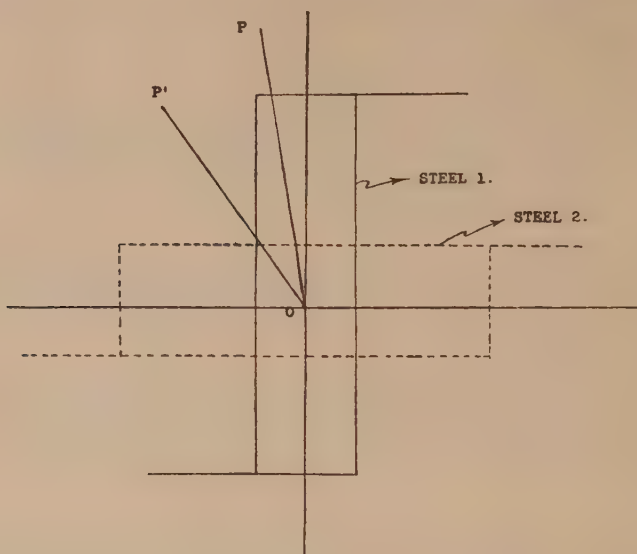


FIG. A.

Mr. Kayser had been obtained with steel and not cast iron magnets; he hoped, however, to determine the "permanent magnet properties" of some of his specimens in the hardened state.

Iron and Steel Institute.

ANCIENT IRON FROM RICHBOROUGH AND FOLKESTONE.

BY J. NEWTON FRIEND, D.Sc., Ph.D., F.I.C. (BIRMINGHAM),
AND W. E. THORNEYCROFT, B.Sc. (BIRMINGHAM).

THE recent excavations at Richborough Castle, near Sandwich, Kent, once the site of an important Roman naval station known as Rutupiae, have revealed many features of interest. The work has been carried out under the ægis of the Society of Antiquaries, Mr. Bushe Fox, Inspector of Ancient Monuments, having charge of the operations. Rutupiae is frequently referred to by early Roman writers, and the neighbouring coast was famous for its oysters, which appear to have been held in high esteem at Rome. The first Roman settlement ¹ probably dates from soon after the invasion of Claudius in A.D. 43, and a more extensive occupation followed towards the close of that century.

Through the kindness of Mr. Walter G. Klein the authors have been enabled to examine a considerable number of specimens of iron from the excavations, which specimens may be divided into two groups, namely :

A. Iron nails, *certainly* of Roman origin.

B. Pieces of iron of various shapes, and in various stages of corrosion, most *probably* of Roman origin, but *possibly* somewhat later.

A. ROMAN IRON NAILS FROM RICHBOROUGH.

Three of these were received, from 10 to 15 centimetres (4 to 6 inches) in length, and are shown in Fig. 1 (Plate XXII.). They were coated with brown rust, more or less contaminated with earthy matter. Beneath this was a layer of hammer scale. One of the nails was sawn through, as indicated by the lines in Fig. 1, the central portion being filed into cylindrical form and tested for resistance to corrosion, the two ends being reserved for analysis and micrographic examination. The coating of brown, hydrated rust was very thin and appeared to "grow" from the hammer

¹ See the Official Guide to Richborough Castle, 1924.

scale beneath, as if this latter had, during the lapse of centuries, undergone slow superficial oxidation and hydration to form rust. The hammer scale varied in thickness from a thin film to about 1 millimetre, and enclosed an irregular bar of iron roughly 0.7×0.5 square centimetre in cross-section. The analysis is given in the fourth column of Table I.

TABLE I.—*Analyses of Richborough and Folkestone Irons.*

1.	2. Modern Mild Steel I.	3. Modern Mild Steel II.	4. Richboro' Nail I. Roman.	5. Richboro' Nail II. Probably Roman.	6. Folkestone Roman Nail.
Carbon	0.080	0.080	0.080	0.070	0.120
Silicon	0.170	0.068	... ¹	... ¹	... ¹
Manganese	0.360	0.370	nil ²	nil	nil
Phosphorus	0.040	0.007	trace	nil	0.001
Sulphur	0.025	0.070	0.046	nil	0.034

¹ Not determined. Value too uncertain in consequence of slag inclusions.

² That is, none detectable in the small pieces available.

Micrographic Examination.—The metal was irregular in structure, some portions showing a typical ferrite structure, with only small amounts of pearlite. The more highly carburised portions showed varying structures, of which Fig. 5 (Plate XXIII.) is one of the most interesting.

Corrosion Tests.—A cylindrical piece of iron was cut from the same nail 5.7 centimetres in length and 0.7 centimetre in diameter. This was placed in an alternative wet and dry corrosion tank, together with a piece of modern mild steel—Steel II., Table I.—cut as closely as possible to the same dimensions. After two months the specimens were removed, cleaned, and weighed, with the following results :

TABLE II.—*Corrosion of Roman Iron from Richborough Castle.*

Alternate wet and dry (two months).

	Roman Iron.	Mild Steel II.
Original weight, grammes	15.1230	16.5590
Loss in weight	0.2430	0.4190
Relative corrosion	58	100

Both specimens were pitted, the Roman iron being slightly the worse of the two. It is very interesting that the total loss in weight of the Roman metal should only approximate to half of that of the modern metal. This point is referred to again in the sequel.

B. PIECES OF IRON, PROBABLY ROMAN, BUT POSSIBLY
LATER, FROM RICHBOROUGH.

A selection of these is shown in Figs. 2 and 3 (Plate XXII.). In addition to these were several nails, from 10 to 18 centimetres in length, with well-defined heads. They were coated with brown rust, beneath which was a thicker layer of black material, presumably hammer scale, ranging from 0.5 to 2 millimetres in thickness. The centre core of metal was roughly rectangular in section, measuring 0.4×0.5 square centimetre. The analysis of one of the nails is given in Table I., column 5. It was remarkably pure iron, and micrographic examination revealed in most places an almost pure ferrite structure similar to that possessed by the Roman iron found at Corstopitum.¹

The hammer-shaped piece of iron shown in Fig. 2 was 18 centimetres (7.2 inches) in length and weighed 229 grammes. It was thickly coated with earthy rust; beneath was a layer of hammer scale about 0.3 centimetre thick, with a small core of iron, roughly 0.4 by 0.5 square centimetre, which, however, did not continue all the way along the length of the bar; the lower end consisted entirely of the magnetic oxide, and readily snapped off in the vice. The cross-section about half-way up the specimen is shown in Fig. 9, drawn to scale.

The ring shown in Fig. 2 weighed 19.4 grammes and consisted of an external layer of brown rust, a thin layer of magnetic oxide, and a good core of metallic iron. Its external diameter was 4.0 centimetres, and the mean diameter of the metal was 0.75 centimetre. Micrographic examination showed an irregular structure. In certain parts pearlite and ferrite were fairly evenly distributed. At other places there had evidently been partial decarburisation. It was interesting to determine, if possible, how

¹ See Plate III. by Louis and Dean, *Journal of the Iron and Steel Institute*, 1912, No. I. p. 128.

the ring had been made, two simple methods suggesting themselves—namely, (1) welding the ends of a small bar, or (2) by working a hole through a disc. At one part of the ring a distinct crack was visible, as shown in Fig. 6 (Plate XXIII.). This, however, did not pass right through the metal but disappeared on further grinding. No further evidence of a weld was obtained.

The curious piece of iron shown in Fig. 3 weighed 450 grammes, and when sawn through at A showed (Fig. 4) that it consisted of a bundle of bars which had apparently been “welded” together, with thick layers of impurity between. The cementing impurity

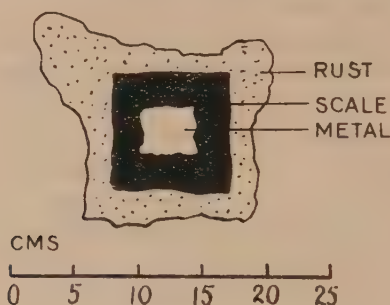


FIG. 9.

was surprisingly hard. Analysis showed it to contain 45·47 per cent. of iron and 24·54 per cent. of insoluble material, mainly silica.

Further examination of A showed that the crudely welded bar had been bent round into the V shape, several small pieces shaped like a letter U being extracted from the mass after the cementing material had been broken away.

C. ROMAN IRON FROM FOLKESTONE.¹

In August 1923, East Cliff, Folkestone, was definitely located as a Roman site, and excavation was undertaken the following April by the Folkestone Corporation, under the direction of Mr. S. E. Winbolt. Foundations of two separate villas of unequal size were laid bare, and it was evident that most of the windows of the larger one had commanded an uninterrupted view across the

¹ For particulars of the excavations see “Roman Villa Site, East Cliff,” by S. E. Winbolt (2nd edition, 1924). Issued by Borough of Folkestone. Also “Roman Folkestone,” by S. E. Winbolt (Methuen, 1925).

Straits to Gessoriacum—the modern Boulogne—which, for nearly two and a half centuries, was the headquarters of the fleet organised by the Romans to protect the Channel. The site under discussion was occupied by the Romans before the end of the first century, namely A.D. 90, and was probably evacuated about the time of the Saxon raids, *circa* A.D. 388. Apparently it is the only seaside Roman villa site on the Kentish coast. It was not expected that rich finds would be made during the excavations, nevertheless many objects of interest were unearthed, the best of which repose in the Folkestone Museum. These include coins, pottery, and objects of bronze and iron.

Amongst the iron objects listed by Mr. Winbolt are the following :

1. Stylus of iron, 4 inches long, with top end flattened for erasing.
2. Iron key, 5 inches by $2\frac{3}{4}$ inches, with a ring at end of handle, and two wards, one broken.
3. *Cutter* (or share) of plough, with big iron socket into which wooden beam was fitted.
4. A big iron cramp, 5 inches by $2\frac{1}{2}$ inches.
5. An instrument like a big chisel with tang for handle ; length, 8 inches.
6. Two choppers with tangs for handles.
7. A round, tapering instrument, perhaps for boring holes ; about 3 inches long, with tang for handle.
8. Curved part of two stirrups.
9. Ring, $1\frac{1}{2}$ inch diameter.

Some of these are shown in Fig. 10, which is reproduced from Mr. Winbolt's "Roman Folkestone," by the courtesy of the author and the publishers.

In addition to these, of course, were many odd pieces of metal, nails, &c., and some of these, through the courtesy of Mr. Isaac E. Lester and of Mr. Winbolt, we have been able to examine. The nails were of various shapes and kinds, ranging from 4·5 to 11 centimetres in length and from 0·6 to 2·0 centimetres across. In the main, however, they were somewhat more slender than the corresponding samples from Richborough. One of the best nails was sawn in two, one portion being tested for corrosion, the other examined micrographically and chemically. All the nails were coated with rust of the usual brownish, earthy character, beneath which was a layer of varying thickness of hammer scale. In the case of one nail, the most slender of all, there was no metallic iron. A second nail had a thin core of metallic iron no thicker than a small sewing-needle. Other nails had varying quantities of

metallic iron in their cores, though not always continuously

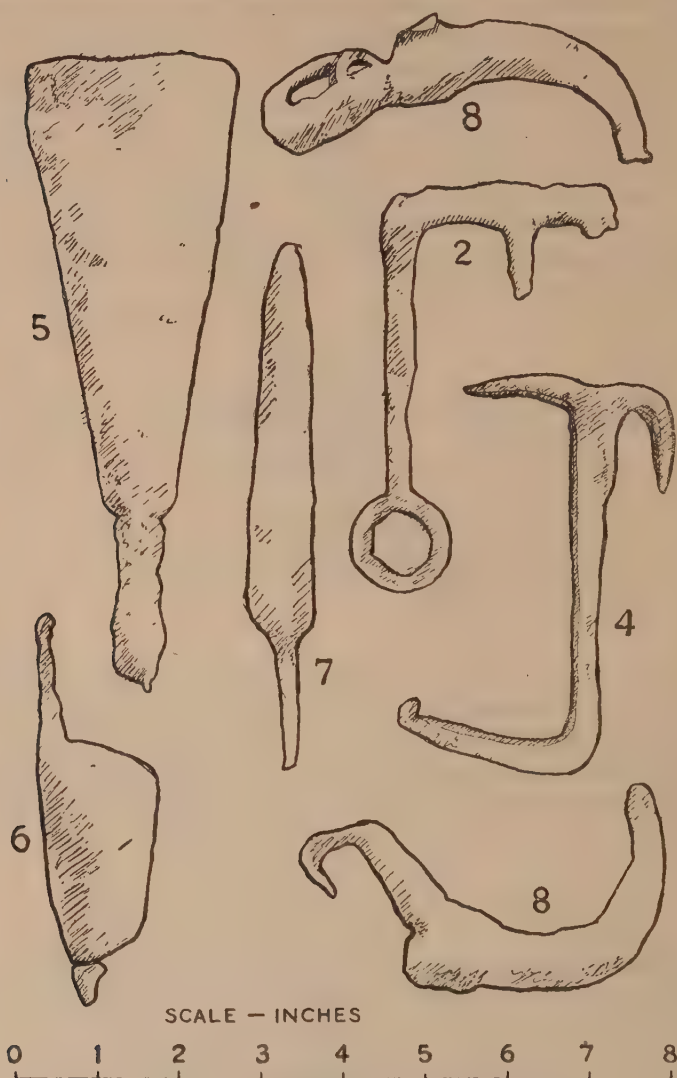


FIG. 10.—Iron objects to scale, except 7, which is $3\frac{1}{4}$ inches long.

throughout their length. They must therefore have been of very uncertain strength even when freshly made.



FIG. 1.—Roman iron nails from Richborough Castle.



FIG. 2.—Iron from Richborough Castle.



FIG. 3.—Iron from Richborough Castle.



FIG. 4.—Cross-section at A—FIG. 3.

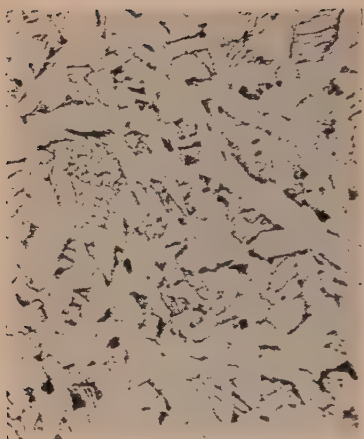


FIG. 5.—Roman iron from Richborough Castle. $\times 120$.

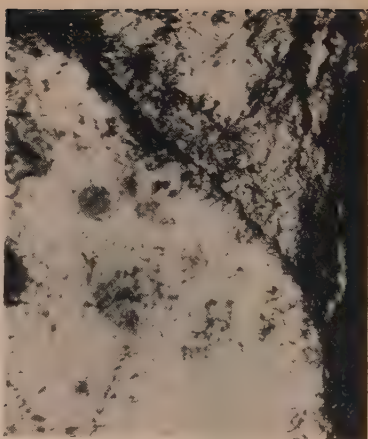


FIG. 6.—Microsection of iron ring from Richborough Castle. $\times 120$.



FIG. 7.—Roman iron from Folkestone. $\times 350$.

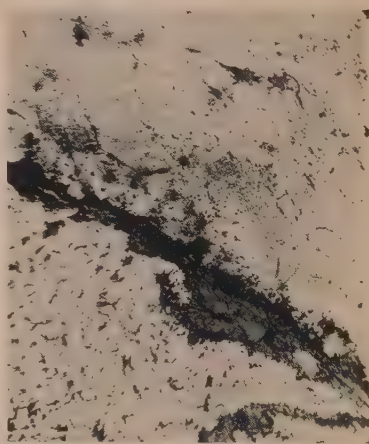


FIG. 8.—Folkestone iron. $\times 120$.

Micrographic Examination.—This showed the metal to be very irregular in structure, and two typical sections are shown in Figs. 7 and 8. The latter shows a crack or “weld,” probably more or less filled with oxide. One side of the metal is partly decarburised and shows the ferrite structure fairly well, the grain boundaries being faintly discernible. Further from the crack the pearlitic areas increase, some as shown in Fig. 7. In general, the metal resembles that used in the construction of the iron beams of the Black Pagoda at Konarak, India,¹ but which dates back only to the thirteenth century.

The analysis of the metal is given in Table I., column 6.

Corrosion Tests.—Owing to the small size of any pieces obtainable from the nails, it was realised that no corrosion tests carried out with them would be sufficiently reliable to be of value. Some weeks later, however, Mr. Winbolt was able to lay a further small supply of iron at our disposal, and a roughly rectangular sheet, 4.5×1.4 square centimetres in area and 0.34 centimetre thick, was obtained, and allowed to corrode in an alternate wet and dry tank for three months along with a piece of mild steel—for analysis see Table I., column 2—cut as closely as possible to the same size. It was very difficult to obtain a satisfactory surface on the Roman iron in consequence of irregularly distributed laminated areas of slag or oxide, and the tendency of the metal to peel off from these in thin layers.

The results obtained were as follows :

TABLE III.—*Rate of Corrosion of Roman Iron from Folkestone.*
Alternate wet and dry (three months).

	Roman Iron.	Mild Steel I.
Area exposed in square centimetres.	15.0	15.0
Original weight in grammes	13.1274	13.0546
Final weight.	12.7970	12.5872
Loss in weight	0.3304	0.4674
Relative corrosion	70.7	100
Density at 12.5° C.	7.4024	7.8468

¹ Friend and Thorneycroft, *Journal of the Iron and Steel Institute*, 1924, No. II. p. 313.

The Roman iron is again distinctly less corrodible than the modern metal. It was deeply pitted, and it seemed as though the pits tended to end at the laminations, and not to pass indefinitely through the metal, as frequently occurs in modern homogeneous mild steel. Probably, therefore, it is the irregularly laminated structure that assists in the preservation of these early specimens. The low density of the metal is undoubtedly largely due to the presence of hollows and slag or oxide inclusions.

In conclusion, the authors desire to thank the Government Grant Committee of the Royal Society for a grant which has enabled them to make this microscopic study.

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DISCUSSION.

Sir ROBERT HADFIELD, Bart. (Past-President), in opening the discussion, thought the paper would prove of fascinating interest to many of the members; it was particularly so to himself because, some of the older members might remember, he read a paper to the Institute in 1912 entitled "Sinhalese Iron and Steel of Ancient Origin." Just after he had compiled that paper he was fortunate enough to receive, through the kindness of Sir John H. Marshall, Director of Archæology in India, a specimen of the famous Delhi pillar, an ancient monument of extraordinary interest. It was made somewhere about the year 300 A.D.; in other words, it was over 1600 years old. He had very much pleasure in handing to the President for inspection a specimen of the pillar, which he was sure would prove of interest. He was able to add to his paper in 1912 particulars showing the composition of the pillar, namely, 0.08 per cent. carbon, 0.046 per cent. silicon, 0.006 per cent. sulphur, 0.114 per cent. phosphorus, no manganese; other elements, including copper, 0.034 per cent.; nitrogen, 0.032 per cent.; iron actually determined, 99.72 per cent. It was 24 feet in length, 16½ inches in diameter at the foot, and 12½ inches in diameter at the top, weighed nearly 6½ tons, and was most beautifully ornamented. A short time ago he had a model made of the pillar, a photograph of which he had brought with him for the inspection of the members.

That pillar completely proved the statement of the authors that some of the ancient iron seemed to possess less tendency to corrosion than modern wrought iron. The specimen of the pillar proved that it was a material more free from any inclusions than any other iron he had met with. His laboratory staff at Sheffield had had a very long experience of metallographic specimens, and he did not think they had ever seen anything to equal that specimen. It was much better than Swedish charcoal iron; his own standard for various experiments, electrical and other, had always been certain Swedish charcoal iron, giving 99.98 per cent. iron. That was better than the specimen of the Delhi pillar, because the latter contained 0.114 of phosphorus; in that respect it was not so pure as the Swedish charcoal iron, but it was entirely free from inclusions.

Metallographers would, he thought, be interested in the photomicrographs, one of which was reproduced here (Fig. B), showing that ancient iron was less corrodible than modern metal, and also that some method was known 1600 years ago for obtaining iron free from inclusions. That was exceedingly important, because he believed inclusions were the basis of corrosion; iron would always be subject to oxidation, but it would be much more resistant to corrosion when free from inclusions than when containing them. The

proof positive of that was in the Delhi pillar. How it was made was not known; the common theory was that it was welded up in its long length piece by piece, but it was apparent that to weld up an article 16 inches in diameter was very difficult, considering the type of smith's



FIG. B.— $\times 50$. The structure consists of large grains of ferrite with a very small portion of cementite, sometimes located in the grain junctions and occasionally in the ground mass.

A smaller grain structure, independent of the larger one, is more or less faintly traceable. There are also a large number of small lines, which at higher magnification are shown to have a regular formation and appear related to the smaller grain structure, and may be due to secular effects, that is, ageing.

On reheating a portion of the specimen to 900°C ., the whole of this fragmentary grain structure is made to disappear, leaving only large clear-etching ferrite grains.

The specimen is remarkably free from slag and other inclusions, and is evidently a very pure iron.

fire then used. It certainly was extraordinary to find that, in spite of all the scientific advances that had been made, the Delhi pillar was, as far as he was able to judge (and he made the statement after weighing his words very carefully), of a better quality than anything they were able to produce to-day. Perhaps a certain type of metallurgical art had died out, or its secrets had been hidden from the modern industrial world. Mr. Keenan had stated in his paper that Indian

coal was particularly high in ash content and therefore particularly impure. A fuel of that kind, therefore, could not have been used; those concerned must have worked entirely with charcoal. Even then one would have thought that Swedish charcoal iron would have been more free from inclusions than the sample of the Delhi pillar. Certain parts of the pillar underground had corroded, no doubt on account of the damp nature of the ground, showing that under certain conditions the metal was corrodible.

Professor H. LOUIS (Vice-President) said he ventured to join issue with Sir Robert Hadfield on the subject of the corrodibility of old iron. His own experience was that it was very much a question of the atmosphere and of the soil. He thought the Delhi pillar had resisted corrosion for so long on account of its being in the wonderful Indian climate. He had just handed to Dr. Desch a number of specimens which he had been fortunate enough to obtain from Rudchester, the latest Roman excavation in the north of England, a few miles out from Newcastle. Some of those pieces of iron were so badly corroded that the first sections that Dr. Desch made showed no iron at all; they were completely converted into the hydroxide. In other parts fragments of the iron were still preserved. He did not think, therefore, the conclusion must be jumped to that the Romans possessed some wonderful secret knowledge of the metallurgy of iron unknown at the present time, but further investigation was needed before that could be accepted as a fact. The samples were now in the hands of Dr. Desch, and he hoped before very long that gentleman would be able to communicate to the members the result of his examination.

Mr. H. G. GRAVES (Bedford) said that he had seen most of the specimens of ancient iron in India. The Delhi column was almost untouched by rust; there was a patina all over it just like bronze, which, at a first glance, it resembled. The whole of the pillar that was exposed was almost rustless. There were, however, throughout India other large pieces of iron that were made at more or less the same time, A.D. 300, or 400 or 500 years later, such as the great beams in the Temple at Konarak, about which he read a paper some years ago. These were strewn about the ground, partly protected from the atmosphere, partly exposed to the sun, and partly buried in the ground. Some were rustless, but most of them were considerably corroded, while some showed badly rusted portions with neighbouring parts quite free of rust. He could not think that the corrosion depended entirely on the composition of the metal or on the way in which it was prepared, but that it must be largely due to the surrounding circumstances, such as the air, and the salt in the soil.

Mr. ARTHUR MARKS (Dudley) thought a contribution on the question of the corrosion of steel might not be inopportune in view of the wide

experience he had had at sea. At sea probably one of the most important points for consideration was the rate at which corrosion would occur. He had examined a large number of Atlantic and other liners for corrosion, and had made many electrical and other determinations of the condition of ships' hulls. Those investigations, extending over many years, proved that the two important facts which arose were, first, that the corrosion was due primarily to segregation in the steel, and, where other corrosion effects occurred on ships, they could be attributed to the passing out of electrical energy from the hull while it was in an anodic condition. It was usual at the present time to protect the condenser tubes of a ship by some means or other, either chemical, mechanical, or electrical, the latter being perhaps one of the most dangerous ways. In examining cases of corrosion which occurred at sea, it was necessary to determine carefully whether such stray currents were possible, and whether the hull of the ship had become anodic, owing to some electrical cause within the vessel. Most electrical engineers would say that the corrosion of the hull of a ship was not due to the electrical machinery, but in view of the low voltages which were necessary for corrosion it was desirable to take measurements extremely carefully. In measuring a vessel which was 200 yards long from end to end and testing its electrical condition, it was possible to detect differences of potential which were quite sufficient to cause rapid corrosion. But, putting those causes aside, he had made investigations in other instances in which the corrosion that occurred in a $1\frac{1}{4}$ inch steel plate on the side of a ship took place in patches. It was possible in some cases to push a knife into the corrosion; in other cases the corrosion was removed entirely by passage through sandy water or by being rubbed away by the ashes ejected from the ash-ejector along the ship's side. In those cases there was undoubted evidence that the cause of the patchy corrosion was due chiefly to carbon segregation. It was possible to get in a rolled plate on a ship's side patches a foot in diameter in which the carbon might differ very considerably from another portion adjacent to it in the plate; and the chief cause of that corrosion, so far as he had determined it over an extensive experience, was the segregation of the constituents. In cases of rapid corrosion in bronzes at sea, it was also usually found that the segregation and rapid corrosion went along the crystal boundaries in a similar, although less marked, manner; the results, however, were equally disastrous. The essential fact was that the knowledge of the manufacture of steel was at present not sufficient to give a perfectly uniform material, but when that ideal was attained he thought one of the worst troubles of the shipowner would be eliminated, namely, corroded plates.

Mr. C. E. STROMEYER (Manchester) thought that when objects of the kind described in the paper were found underground they should be reconstructed. He was not a sufficiently expert chemist and metallurgist to know whether the following plan could be carried out, but he

would suggest that when buried lumps of rust were found they should be packed into airtight metal boxes and heated while a stream of hydrogen was passed through the box in order to reduce the hydroxide of iron to iron. Some idea of the original form of the objects would then be obtained. It seemed to him that unless some process of that kind were used we should never be able to determine the earliest date at which iron implements came into use.

Mr. T. HENRY TURNER (Birmingham) said there were at the University of Birmingham a number of samples of Roman remains similar to those described by the authors. He had sectioned one of them, a Roman nail, by mounting it in white metal before the rust was removed. It showed, in agreement with what Professor Louis had said, that there were three distinct forms of metal present and not pure iron only. Parts of the nail were pure iron, parts steel, and parts were impure iron. Under the head, where the metal had been cold-worked, the deformation of the crystals could still be seen, evidence that the deformation of a crystal would remain for a thousand years or more under ordinary atmospheric conditions and temperatures. That was quite an interesting scientific fact. [The nail referred to was exhibited to many members at the reception held later at the University, and a number of them took the opportunity of examining it under the microscope.]

CORRESPONDENCE.

Dr. F. JOHNSON wrote that he had read the paper with much interest. The hammer-shaped piece of iron (Fig. 2) was described by the authors as being "thickly coated with earthy rust; beneath was a layer of hammer scale about 0.3 centimetre thick." The description "hammer scale" did not seem justified. An iron implement could not have left the hands of the smith with a layer of scale one-third of a centimetre in thickness. Such a layer might have been formed as the result of prolonged heating, either accidental or otherwise, but it appeared to be more probable that the layer consisted of an accretion of rust, consolidated under pressure during the centuries.

The AUTHORS wrote, expressing their thanks for the reception accorded to their paper.

Iron and Steel Institute.

EQUILIBRIUM AT HIGH TEMPERATURES IN
THE IRON-CARBON-SILICON SYSTEM.

BY M. L. BECKER, B.MET. (UNIVERSITY OF MANCHESTER).

INTRODUCTION.

IT is now well known that the condition of the carbon is the principal factor determining the mechanical and some physical properties of cast iron, and that therefore the possibility of control of this condition is of considerable interest in the foundry. The concentration of carbon in solution in iron, in equilibrium with free carbon, varies appreciably with temperature, so that exact knowledge of this equilibrium is essential when considering the effect of rate of cooling, or subsequent heat treatment. Many investigators have studied the question of stable equilibrium in commercial alloys and in the pure iron-carbon alloys, but very little work has been published concerning the influence of varying amounts of a third element upon the latter.

Charpy and Cornu-Thenard ⁽¹⁾ have studied the influence of silicon on the solubility of carbon in iron. These investigators used a series of cast alloys containing roughly 2 per cent. of carbon, and varying in silicon from 2.23 per cent. to 6.77 per cent. First of all, the carbon was precipitated as graphite by annealing the alloys at 1000° C. for three hours and cooling slowly (80° C. per hour). This was followed by heating the alloys at a constant temperature varying from 600° C. to 1000° C. for one to three hours, and finally quenching. The specimens were analysed for total carbon and graphite, the difference being taken as the carbon in solution at the temperature of the experiment. Charpy and Cornu-Thenard's general conclusions are given in Table I., although a reference to the original paper will show that the actual experimental values are to some extent inconclusive. Probably this was due to the method of analysis, which, although generally considered the most reliable, is open to some objections when used for small specimens where the percentage of graphite frequently varies

in different parts. The experiments to be described have been conducted under different conditions in order to gain further knowledge regarding equilibrium in this system.

Charpy,⁽²⁾ Iokibe,⁽³⁾ and Northcott⁽⁴⁾ have shown that temper carbon is indistinguishable chemically and physically from graphite, and it is therefore justifiable to assume that the two are identical. Upon this basis it seemed advisable to investigate the equilibria by cementing in graphite a series of pure iron-silicon alloys until saturation was reached. That the carburisation of iron by solid carbon depends, from the practical standpoint, upon the presence of a gas phase has been proved by several investigators, notably Guillet and Griffith,⁽⁵⁾ Giolitti and Astorri,⁽⁶⁾ Weyl,⁽⁷⁾ and

TABLE I.—*Results obtained by Charpy and Cornu-Thenard.*

Silicon per Cent.	Carbon per Cent. in Solution.				
	600° C.	700° C.	800° C.	900° C.	1000° C.
2.23	0.6	0.8	1.1
3.16	0.7	0.9
4.22	0.2	0.7
5.84	0.3
6.77	0.2

Charpy and Bonnerot.⁽⁸⁾ When, as in the experiments to be described, the carburising chamber is first filled with air this gaseous vehicle will consist of nitrogen and the two oxides of carbon in equilibrium with carbon. If the theory of Honda and Murakami⁽⁹⁾ be accepted, namely, that graphitisation in iron-carbon alloys is largely due to the presence of the two oxides of carbon in the solid metal, it becomes increasingly evident that the equilibrium at any temperature with respect to carbon in solution should be the same whether graphitising a high carbon alloy or carburising a low one. In the case of the pure iron-carbon alloys experimental evidence to this effect is not lacking. Charpy,⁽¹⁰⁾ by cementing iron in wood charcoal at 1000° C., obtained about 1 per cent. of carbon in solution, which figure agrees closely with the value he obtained by annealing pure white or grey iron at the same temperature. Gutowsky⁽¹¹⁾ carried out carburising experiments

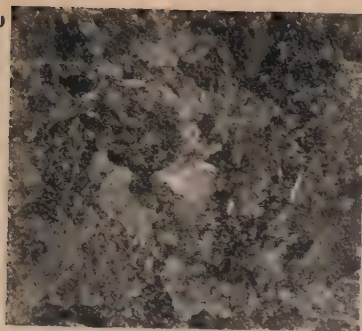


FIG. 6.
Armco. Carburised. 940°C.
× 250.



FIG. 7.
1.33 % Si. Carburised. 940°C.
× 250.



FIG. 8.
2.54 % Si. Carburised. 940°C.
× 250.

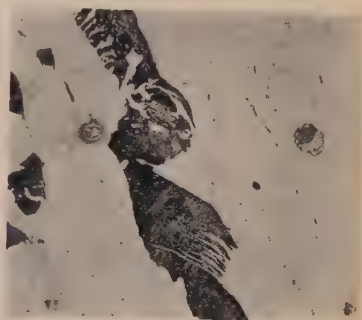


FIG. 9.
4.22 % Si. Carburised. 940°C.
× 250.

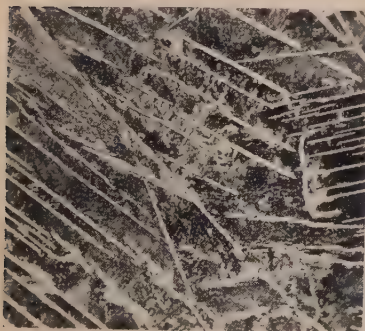


FIG. 10.
Armco. Carburised. 1100°C.
× 250.

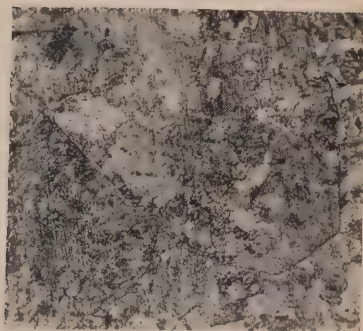


FIG. 11.
1.33 % Si. Carburised. 1100°C.
× 250.

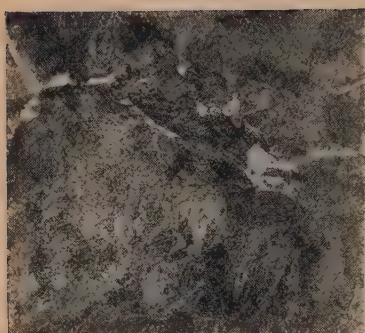


FIG. 12.
2.54 % Si. Carburised. 1100°C.
× 250.

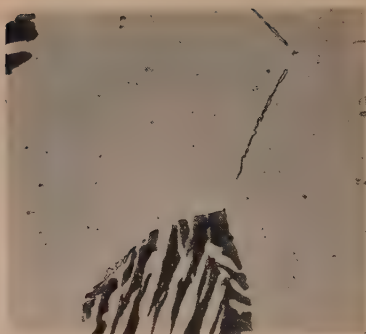


FIG. 13.
4.22 % Si. Carburised. 1100°C.
× 250.

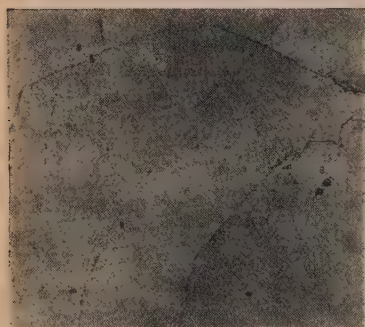


FIG. 14.
1.33 % Si. Carburised. 1100°C.
(Etched Sod. Picrate.) × 250.

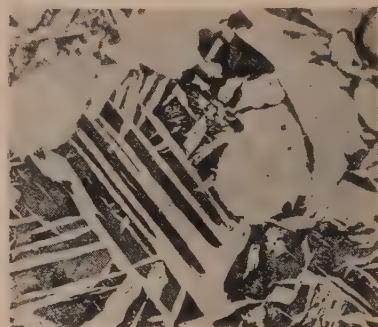


FIG. 15.
4.22 % Si. Carburised. 1100°C.
(Experiment C5.) × 250.

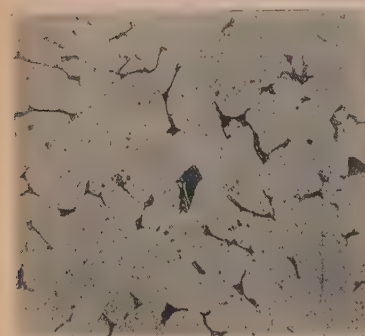


FIG. 16.
Armco. Carburised. 910°C.
(Experiment C14.) × 250.

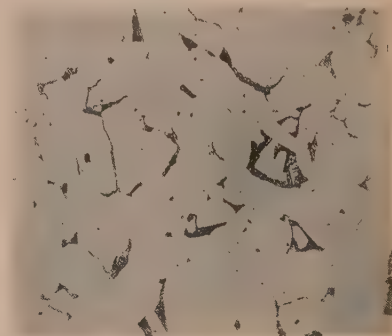


FIG. 17.
American washed iron. Decarburised.
910°C. (Experiment C14.) × 250.

on shavings of iron, but obtained high results, probably corresponding more nearly with cementite than with graphite equilibrium, on account of the powerful carburiser employed (mixture of amorphous carbon and barium carbonate).

CEMENTATION EXPERIMENTS.

Armco iron and three pure iron-silicon alloys containing approximately $1\frac{1}{2}$, $2\frac{1}{2}$, and 4 per cent. of silicon were used as basis materials in the present investigation. The analyses of these materials are given in Table II. :

TABLE II.

Material.	No.	C.	Si.	Mn.	S.	P.
Armco . .	...	0.03	0.01	...	...	...
Silicon alloy .	$1\frac{1}{2}$	0.10	1.33	0.22	0.024	0.032
" " .	$2\frac{1}{2}$	0.07	2.54	0.065	0.030	0.027
" " .	4	0.06	4.22	0.09	0.026	0.025

The silicon alloys were received in the form of strips $\frac{3}{8}$ inch thick and 8 inches wide. The strips were cut longitudinally into bars $\frac{3}{8}$ inch square and 8 inches long, which were then turned down into rods $\frac{5}{16}$ inch diameter. Short lengths about $1\frac{3}{4}$ inch long were used in each experiment. The Armco, which was received as $\frac{7}{16}$ -inch rod, was turned down to $\frac{5}{16}$ inch for the sake of uniformity, but it was subsequently found that the high rate of carbon penetration in the case of iron containing no silicon more than counterbalanced the effect of the increased depth to be cemented during each experiment. The cementing medium was prepared from graphite electrodes, only that portion passing through a 90-mesh sieve being used. The powder was not subjected to any purifying treatment, as it was found that a sample which had been used for carburising specimens at 1000° C. contained 99 per cent. of carbon, and that the remaining 1 per cent. in that instance was due to the presence of iron scale. It cannot, however, be assumed that the graphite was entirely free from impurities such as occluded gases, evidence of which has been frequently noted in connection with other work.

A section of the furnace used (Fig. 1) is included in order to show the comparatively long winding and uniform temperature obtained over the entire length of the graphite carburising box. The latter with lid and also the ends of the heat-insulation plugs were turned from the same electrodes as were used in the preparation of the carburiser. The pressure in the furnace was the same as that of the atmosphere. Under these conditions there was practically no difference in temperature from one end of the carburising box to the other, and it was assumed that, given sufficient time, the gas surrounding the specimens would reach

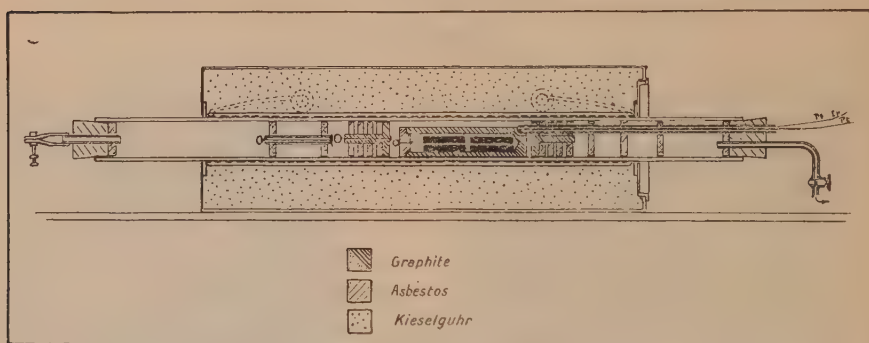


FIG. 1.—Carburising Furnace.

equilibrium with graphite at the temperature of the experiment, and that any convection currents at the ends of the furnace would not interfere with the establishment of that equilibrium. In order to find out the variations in temperature due to slight fluctuations in the voltage, a 300-hour continuous record was taken during the carburising at 1100°C . It was found that the rise and fall of temperature only amounted to $\pm 5^{\circ}\text{C}$., except at a certain hour each day when for a period of two hours out of the twenty-four the temperature reached 10°C . above the normal.

It was realised during the early stages of the work that the time required for saturation would be considerable, and that furthermore some method would have to be adopted in order to find out when equilibrium had been reached. Campbell, Fink, and Ross,⁽¹²⁾ when obtaining equilibrium in dry hydrogen between

pure iron and steels varying in carbon content, found that the increase or decrease in carbon content could be determined by weighing the individual specimens before and after the equilibrium treatment. A similar method was adopted in the present experiments, it being found convenient to weigh the specimens after approximately 40, 160, and 300 hours, the intention being to allow an ample margin of time undisturbed during the final stage.

At the beginning of each experiment and after each weighing the specimens were packed in graphite in the carburising box, and the whole introduced into the furnace held at the required temperature. The time at which the temperature of the box reached 900° C. was taken as representing the commencement or continuation of carburisation, although from one to three hours usually elapsed before the temperature of the experiment was reached. At the end of each stage the box containing the specimen was withdrawn and allowed to cool in air. When cold the specimens were rubbed free from adhering graphite, washed in water, dried, and weighed.

Table III. gives the weight of specimen carburised, and the

TABLE III.—*Mean Carbon Content calculated from Increase in Weight during Carburisation.*

Experiment No.	Temperature, Degr. C.	Material.	Initial Weight of Specimen (Grammes).	Carbon per Cent.			
				Actual (by Analysis).	Apparent (from Increase in Weight).		
					0 Hrs.	74 Hrs.	145 Hrs.	313 Hrs.
C6	940	(1)	32.4655	0.03	0.68	0.82	0.90
		Armco (2)	18.7650	...	...	0.90	0.91
		(3)	11.5890	...	0.88	0.95	0.98
		1.33% Si	18.1665	0.10	...	0.81	0.81
		2.54% Si	17.6880	0.07	...	0.42	0.50
		4.22% Si	16.0150	0.06	...	0.17	0.17
C17	1100	Armco	19.2455	0.03	1.32	1.47	1.53
		1.33% Si	18.9470	0.10	1.07	1.24	1.38
		2.54% Si	20.3575	0.07	0.52	0.60	0.65
		4.22% Si	19.4820	0.06	0.08	0.10	0.10

apparent carbon content at each stage for two temperatures— 940°C. and 1100°C. The values for apparent carbon content have been calculated by adding the percentage of carbon shown

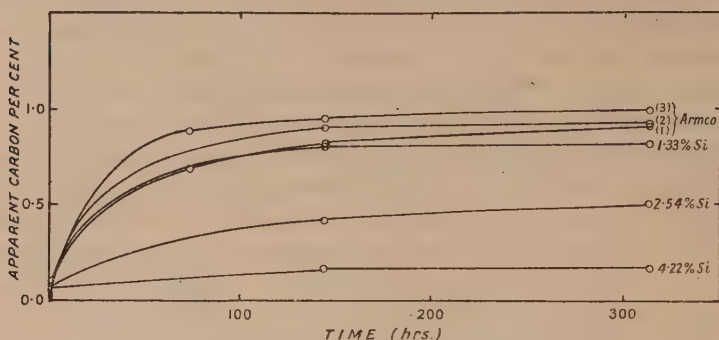


FIG. 2.—Carburisation Curves for 940°C.

by the increase in weight to the initial percentage. These values are shown graphically in Figs. 2 and 3. The dotted line in Fig. 3 is the true carburisation curve for a 30-gramme specimen of Armco

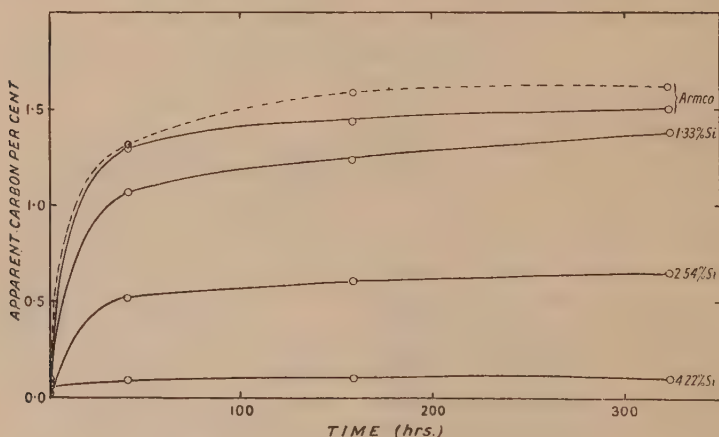


FIG. 3.—Carburisation Curves for 1100°C.

included in experiment C17. The actual percentage of carbon is given in Table IV., experiments C17 (a) and (b), after which it reaches the same value as the 19-gramme specimen in C17 (c).

It will be seen that the percentage of carbon calculated from the gain in weight is not in accordance with the actual percentage determined by analysis, and the appearance of the specimens suggested that these discrepancies were due to an indefinite amount of surface oxidation and consequent scaling. For this reason the curves for the intermediate temperatures are not reproduced, although each indicated that sufficient time had been allowed to ensure the limit of carburisation being reached.

CONSIDERATION OF RESULTS.

The results of sixteen experiments are given in Table IV. Fig. 4 shows graphically the percentage of silicon in the original alloys plotted against the carbon introduced at different temperatures, namely, 900°, 910°, 915°, 940°, 990°, 1045°, and 1100°.

TABLE IV.—*Carbon Content of Carburised Alloys.*

Experiment No.	Temperature. Degr. C.	Duration of Cementation (Hrs.).		Combined Carbon per Cent.			
		Successive Periods.	Total.	Armco.	1.33% Si.	2.54% Si.	4.22% Si.
C7	800	24, 167	191	0	0	0	0
C8	850	67, 65, 45	177	0	0	0	0
C10 (a)	900	24	24	0.17	...	...	...
C10 (b)	900	24, 26	50	0.19	...	...	...
C9 (a)	910	89	89	0.26	0	0	0
C9 (b)	910	89, 116	205	0.26	...	...	...
C14	910	310	310	0.23	...	...	...
C12	915	117	117	0.32	...	...	...
C6	940	74, 71, 168	313	0.81	0.64	0.41	0.06
C15	990	41, 119, 135	295	0.91	0.73	0.55	0.11
C16 (a)	1045	41, 117	158	1.26	...	...	...
C16 (b)	1045	41, 117, 157	315	1.21	0.96	0.66	0.08
C5	1100	72, 96	168	1.61	1.30	0.60	0.17
C17 (a)	1100	41	41	1.30	...	...	...
C17 (b)	1100	41, 117	158	1.58	...	...	...
C17 (c)	1100	41, 117, 166	324	1.62	1.34	0.75	0.09

experiment numbers C10 (b), C9 (b), C12, C6, C15, C16 (b), and C17 (c) respectively. Cylinders of standard size were used in each experiment at temperatures of 915° C. and above, in addition to which at least one specimen of Armco of a larger diameter ($\frac{7}{16}$ inch)

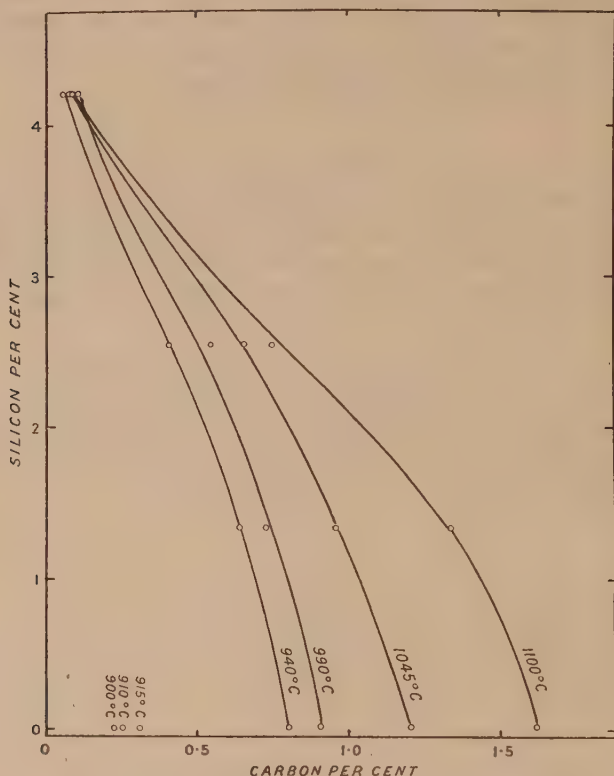


FIG. 4.—Isotherms for Iron-Carbon-Silicon Equilibrium.

was carburised in the experiments at 940° C. and above, bringing the total weight charged to approximately 100 grammes. It should be noted that experiment C5 was abnormal in that about 50 grammes of white iron were introduced into the furnace along with the usual charge to be carburised. The partially annealed white irons were removed at the conclusion of the first period of seventy-two hours, but it is to their presence during the early

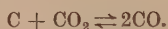
stages of carburisation that the high carbon content of the 4.22 per cent. silicon alloy must be ascribed.

The microstructures of the series carburised at 940° C. are shown on Plate XXIV., Figs. 6 to 9, and of the series at 1100° C. in Figs. 10 to 13. It will be seen that silicon has very little influence on the type of structure apart from increasing the grain-size. No attempt was made to measure the grain growth during carburising. Some difficulty was experienced in the etching of all the carburised alloys in spite of every precaution to avoid staining. The best results were obtained by washing the polished specimen in alcohol both before and after etching in the usual saturated solution of picric acid in alcohol. The pearlite is not particularly well laminated in any of the specimens, but this is quite to be expected in view of the comparatively rapid rate at which they were cooled through the A1 point (approx. 50° C. per minute). Micro Fig. 14 (Plate XXV.) shows the same specimen as Fig. 11 (Plate XXIV.) (1.33 per cent. silicon), etched in alkaline sodium picrate, indicating the presence of excess cementite at the grain boundaries. The distribution of the pearlite in the 4.22 per cent. silicon alloy carburised at 1100° C. in experiment C5 is shown in Plate XXV. (Fig. 15). It is obvious that the carbon content of this alloy (0.17 per cent.) is in excess of the equilibrium content (0.09 per cent.) which gives the structure depicted in Fig. 13. The reason for this difference has already been given. The relative amounts of ferrite and pearlite shown in Fig. 15, corresponding with only 0.17 per cent. carbon, are striking evidence of the effect of silicon in lowering the carbon content of the pearlite eutectoid.

With regard to carburising in graphite at temperatures between 800° and 900° C., preliminary investigation seemed to show that this was either impossible or else that the time required was excessive. For this reason small specimens $\frac{1}{8}$ inch diameter and 1 inch long were prepared and packed in graphite in a short graphite box. The rest of the uniform temperature portion of the furnace was occupied by $\frac{1}{2}$ inch diameter fireclay tubes containing a mixture of graphite and turnings of the materials to be carburised.

In experiments C7 and C8, conducted at 800° and 850° C. respectively, no carburisation was obtained either of the turnings or of the $\frac{1}{8}$ -inch specimens. On the other hand, an appreciable

amount of oxide of iron was formed on the surface of the specimens of Armco, whilst the turnings were oxidised throughout. This effect was so marked after the first period in experiment C8 that a slow stream of nitrogen was passed through the furnace at the beginning of the second and third periods in order to lower the partial pressures of carbon monoxide and carbon dioxide taking part in the equilibrium :



It was thought that the lowering of the pressure and the consequent shift of equilibrium towards the right might keep the conditions away from those of oxidation without seriously affecting the degree of cementation. The result of experiment C8, however, shows that even after this precaution no carburisation took place. Finally, in experiment C13 a specimen of Armco containing 0.26 per cent. of carbon was completely decarburised and oxidised to an average depth of $\frac{1}{32}$ inch by treatment in graphite for 144 hours at 850° C.

Turnings only were used in experiments C10 (a) and (b) at 900° C., the carbon content being estimated by colour. In experiment C9 (a) no carburisation was found on examining the silicon alloys, although the specimen of Armco was carburised appreciably. After magnetically separating the small quantity of graphite powder mixed with the Armco turnings their combined carbon content was determined by wet combustion, giving the value 0.26 per cent. carbon for equilibrium at 910° C. Samples of American washed iron and silicon-bearing white cast iron were introduced along with the Armco in experiment C14 at 910° C. Even after 310 hours the silicon irons were not completely decarburised in the centre, although the outer zone consisted of ferrite. Micro Fig. 16 shows a section of the carburised Armco, whilst Fig. 17 shows an area near the edge of the washed iron. Clearly the carbon contents are practically identical, which demonstrates that a state of equilibrium has been very nearly reached from opposite directions.

From the isothermal diagram (Fig. 4) it is possible by interpolation to obtain for each temperature a series of values for carbon in solution corresponding with anything from 0 to 4 per cent. of silicon. Table V. gives the values found in this way, and Fig. 5 their graphical representation.

TABLE V.

Silicon per Cent.	Temperature (Degrees C.).						
	800.	850.	910.	940.	990.	1045.	1100.
0	0.00	0.00	0.26	0.81	0.91	1.21	1.62
1	"	"	0.00	0.70	0.80	1.03	1.43
2	"	"	"	0.53	0.63	0.80	1.03
3	"	"	"	0.30	0.38	0.48	0.55
4	"	"	"	0.10	0.14	0.14	0.16

On comparing these values with those of Charpy and Cornu-Thenard given in Table I. it will be seen that the agreement is

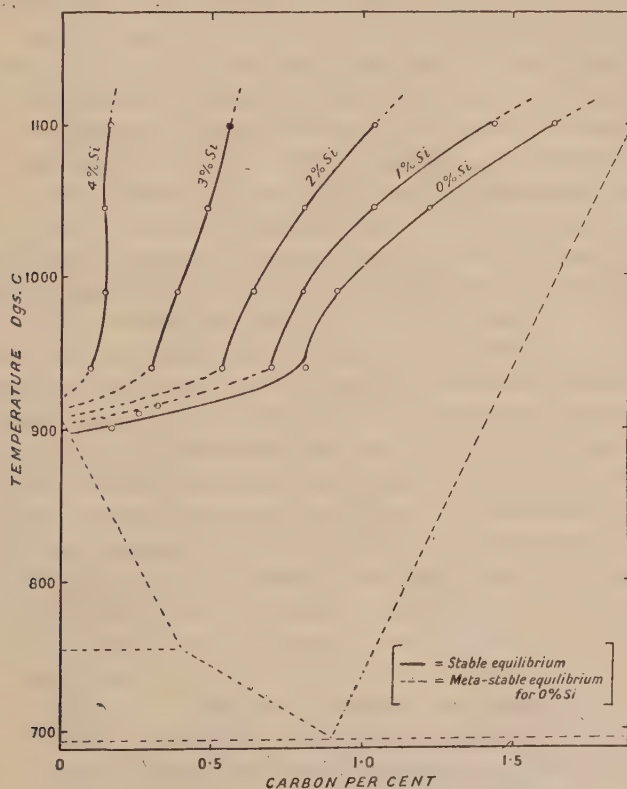


FIG. 5.—Effect of Silicon on the Equilibrium with Graphite.

not good. Apart from the carbon content the analyses of the two series of alloys are very similar and justify a comparison being drawn. According to Charpy and Cornu-Thenard, the values for carbon in solution are in excess of those given in Table V., particularly at temperatures below 950°C . A possible explanation of this seems to be that in the experiments of Charpy and Cornu-Thenard the carbon in solution may not have been completely graphitised before re-solution at a constant temperature. If this be true an indefinite amount of combined carbon would remain in the alloys, and if much in excess of saturation at the lower temperatures it is highly probable that the subsequent annealing at, say, 800°C . for one and a half hours would not suffice to graphitise the excess. This would be particularly true of the alloys containing less than 4.5 per cent. of silicon now under comparison.

That the accuracy of these results may be questioned is also borne out by the fact that one of the authors, Charpy, in conjunction with Grenet,⁽¹³⁾ had previously published a few results showing the influence of silicon on the equilibrium with carbon. Thus at 1100°C . the silicon contents of 0.07, 0.27, 0.80, 1.25, and 2.10 per cent. were associated with combined carbon contents of 1.74, 1.93, 1.26, 1.02, and 1.00 respectively, showing on the whole a good agreement with the values now obtained by carburisation. Later, in a paper to which reference has already been made, Charpy draws the conclusion that in a pure iron-carbon alloy stable equilibrium at 1000°C . is reached when there is 1 per cent. of carbon in solution, which value has also now been confirmed by carburisation. In fact, the carburisation curve for pure iron between 1100° and 940°C . is in good agreement with results which have been obtained by other investigators. Below these temperatures the curve has usually been produced to meet the A3-2 line of the metastable diagram, but carburisation data indicate that the curve bends to the left to meet the A3 line about 900°C .

Theoretically, as Hayes, Diederichs, and Flanders⁽¹⁴⁾ have pointed out, when the curve meets the A3 or the A3-2 line, another phase (ferrite) makes its appearance in the system, thus reducing the degrees of freedom to nought. This results in the simultaneous precipitation of ferrite and graphite forming what has been called the graphite-ferrite eutectoid. If the results obtained by carburisation at 910°C . are the same as those which

would be obtained by very prolonged annealing of, say, white iron at the same temperature, then it would appear that the temperature of formation of the graphite-ferrite eutectoid in the absence of silicon is about 900°C ., and that it contains only approximately 0.05 per cent. of carbon. The effect of silicon would be to raise the temperature of formation slightly without appreciably affecting the composition.

SUMMARY.

1. The effect of silicon upon the stable equilibrium between iron and carbon has been studied by cementing to saturation at various temperatures a series of alloys containing 0.01 to 4.22 per cent. of silicon. The results are plotted in Fig. 5.

2. For pure iron-carbon alloys the values for carbon in solution above 940°C . agree well with those obtained by previous workers using different methods, but below 940°C . they fall lower, until there is no solubility about 900°C .

3. For iron-carbon-silicon alloys, as silicon increases up to 4.0 per cent., the solubility of carbon at any constant temperature between 1100°C . and 940°C . decreases, whilst the effect of temperature in raising the solubility becomes less marked. Below 940°C . the solubility drops rapidly to zero, probably in the neighbourhood of 920°C .

The above research has been carried out during the past year in the Department of Metallurgy of the University of Manchester. It has been extended and completed as one section of a wider field now under investigation for the British Cast Iron Research Association. Thanks are due to the Council of the above Association for permission to publish the later results. The author also takes this opportunity of thanking Professor F. C. Thompson for his kindly supervision and interest during the whole course of the work.

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CORRESPONDENCE.

Mr. E. ADAMSON (Sheffield) wrote that the author was to be congratulated on the extreme care taken in conducting experiments and recording them. Up to the temperatures used by the author absorption of carbon by iron would naturally be slow, and it would be difficult to estimate from the carbon equilibrium diagram the percentages of carbon which iron could absorb whilst still in the solid state. That difficulty was shown by the author himself, for although with increasing temperature there was a greater absorption of carbon at each higher temperature, still the same experiment could not be carried out twice under apparently identical conditions with identically the same results. That was shown by the fact that the author admitted his results did not agree with those of Charpy and Cornu-Thenard.

Naturally if the total carbon could not be controlled under laboratory conditions it was difficult to see how it could be controlled under the working conditions of a blast-furnace, and the author's further work in that connection would be awaited with interest.

The AUTHOR, in reply to Mr. Adamson, wrote that the experiments described in the paper indicated that under the same conditions equal amounts of carbon would be absorbed in solution (compare, for example, experiments C5 and C17(c), Table IV.). The temperature during the experiments was not absolutely steady, and another factor which may possibly have varied was the partial pressure of the carburising medium, carbon monoxide, although it could not be said yet whether that had an appreciable effect upon the degree of carburisation. In spite of those variables the results showed a reasonable consistency, and therefore it was possible to ascertain from the equilibrium diagram (Fig. 5), with a fair degree of accuracy, the amount of carbon which would be absorbed by iron in contact with graphite at any definite temperature within the range of the experiments. The results of Charpy and Cornu-Thenard were not obtained under the same experimental conditions as those of the author, but he referred to them in the paper in order to point out that fact as well as to offer a possible explanation of the discrepancies.

The results given in the paper could not be applied to the problem of total carbon control in the blast-furnace, but, on the other hand, they might be of use to either grey or malleable iron founders who, by varying cooling rates or annealing temperatures, had to meet certain specifications as to the combined carbon content of the finished castings.

The author thanked Mr. Adamson for his interest in the research and comments thereon.

Iron and Steel Institute.

THE CHROMIUM-IRON EQUILIBRIUM IN CARBIDES RECOVERED FROM ANNEALED 2.23 PER CENT. CHROME STEELS.

BY E. D. CAMPBELL* AND J. F. ROSS (ANN ARBOR, MICHIGAN).

FROM many researches on the composition of carbides recovered by electrolysis of annealed steels, it is evident that certain elements, such as chromium, manganese, vanadium, tungsten, and molybdenum, have a stronger affinity for carbon than has iron, so that these elements, when present in steel, will tend to concentrate in the carbides precipitated by annealing, rather than remain in solution in the solvent iron.

The tendency for chromium to concentrate in the carbides was well brought out by the researches of Arnold and Read,⁽¹⁾ and the greater stability of the double carbides of iron and chromium compared with those of iron alone has been shown by the present authors⁽²⁾ in a previous paper.

The object of the present investigation was to determine the atomic ratios of chromium, iron, and manganese in the carbides recovered from annealed steels, in which the atomic ratios of these three elements in the system as a whole was kept strictly constant, the only variable being the carbon content.

In a recent paper one of the authors, in conjunction with G. W. Whitney,⁽³⁾ has described in detail a method by means of which series of small steel bars were prepared in which the atomic ratios of all the metallic elements remained strictly constant while the amount of carbon was varied over the entire range found in commercial steels. The same method was also described in a paper submitted by one of the authors and G. W. Whitney⁽⁴⁾ to the Iron and Steel Institute in 1924.

MATERIALS.

The six small steel bars used for the electrolytic recovery of carbides were derivatives prepared from a commercial chrome

* It was with deep regret that the announcement of the death of Professor E. D. Campbell was received by the Council shortly after the presentation of this paper to the Institute.

magnet steel by the method above referred to. The composition of the original steel was: carbon 0.85 per cent., manganese 0.24 per cent., phosphorus 0.027 per cent., sulphur 0.035 per cent., silicon 0.25 per cent., chromium 2.23 per cent., nickel 0.12 per cent., copper 0.084 per cent., and iron 96.16 per cent. The weight per cent. of carbon, chromium, manganese, and iron in these derivatives, together with the factor used for computing "unit weight" of steel, which for purposes of identification are designated by the carbon content, are given in Table I.

TABLE I.—*Analyses of Steels.*

Steel.	Carbon.	Chromium.	Manganese.	Iron.	Calculated Factor.
0.36	0.36	2.24	0.24	96.63	$\frac{99.64}{99.15} = 1.0049$
0.50	0.50	2.24	0.24	96.50	$\frac{99.50}{99.15} = 1.0035$
0.85	0.85	2.23	0.24	96.16	$\frac{99.15}{99.15} = 1.0000$
1.05	1.05	2.23	0.24	95.97	$\frac{98.95}{99.15} = 0.9980$
1.43	1.43	2.22	0.24	95.60	$\frac{98.57}{99.15} = 0.9942$
1.62	1.62	2.21	0.24	95.41	$\frac{98.38}{99.15} = 0.9923$

CARBIDE RECOVERY.

In the present investigation the carbides were recovered electrolytically in a 4 per cent. (40 cubic centimetres concentrated HCl per litre) solution of hydrochloric acid.

The bars, before electrolysis, were very carefully polished so as to get a smooth surface. It was found that the carbides would tend to flake off if the bars were not perfectly smooth. The bars were about 6 millimetres square and 15 centimetres long. Each bar was sawn near one end about half-way through, thus practically making a small hook by means of which the bars could be suspended. The steel was next washed with alcohol, then with ether, and weighed.

The electrolysis was conducted in a tall cylindrical glass jar which was about $12\frac{1}{2}$ centimetres in diameter and 24 centimetres

high. The cathodes used in the electrolysis were two strips of platinum 1 centimetre wide and 10 centimetres long. The platinum strips were welded to the ends of a platinum wire, so that by making electrical connection to the wire the two cathodes were thus placed in parallel. These cathodes were hung along the sides of the jar and on either side. The bar to be electrolysed was suspended in the centre of the jar by means of a platinum wire connected in the saw cut. Two litres of electrolyte were used to cover completely the suspended bars. By means of a resistance and ammeter in the circuit, the current through the system was adjusted to about 600 milliamperes. The electrolysis was continued for ten to twelve ampere-hours. It was found that an ampere-hour would dissolve away about 1 gramme of iron, and that 12 to 14 grammes of the steel could be dissolved without any danger of the carbides flaking off the bars. In the solution very little hydrogen was evolved from the bar, showing that the acid action on them was very small. No iron was deposited on the cathodes under the conditions used.

The physical appearance of the bars before and after electrolysis was very similar. The accompanying photographs show the bars before and after electrolysis.

Fig. 1 shows an original bar (No. 52) and one which has been electrolysed (No. 53).

Fig. 2 shows the same two bars as shown in Fig. 1, with the carbides removed from bar No. 53.

The fact that a piece of steel is so completely filled with a network of carbides is very clearly shown.

When the electrolysis had proceeded a sufficient length of time, the bar was lifted from the electrolyte and placed in a long porcelain boat containing water. By means of a small iron wire brush, the adhering carbides were removed from the bar. In the filtration of the carbides, a Munroe crucible—that is, a porcelain Gooch with platinum sponge filtering mat—was found to be the most satisfactory. The carbides were next transferred to the crucible by means of a jet of water. After washing well with water, the carbides were washed with a 2 to 3 per cent. solution of sodium carbonate to remove all traces of acid. The sodium carbonate was then washed out with water, which was in turn removed by absolute alcohol. The carbides were finally washed with ether,

care being taken to remove only the excess ether and not draw any air through the carbides. The crucible was then placed in a vacuum desiccator containing sulphuric acid, and the carbides

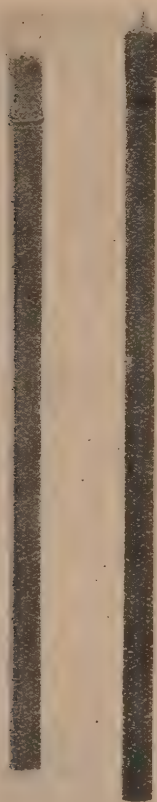


FIG. 1.



FIG. 2.

allowed to dry thoroughly. The entire operation of removing the carbides from the bars and washing them required less than five minutes, and there was very little decomposition of the material in this short interval.

In the cases of the 0.36 steel and the 0.50 steel, the carbides recovered were pyrophorous if air were drawn through the crucible

containing the carbides which were moist with ether. This tendency to decompose so easily was not present in the hyper-eutectoid steels. The pyrophoric nature of the hypoeutectoid steels may be due to the extremely fine state of division of the carbides.

When the carbides were dry they were loosened from the bottom of the crucible and all lumps broken up by means of a small stirring rod. After transferring to a weighing bottle, they were accurately weighed.

In the cases of the carbides recovered from the hypoeutectoid steels, there was apparently some oxidation during the crushing process. The carbides seemed to increase slightly in bulk upon being loosened, but there was no temperature change in the crucible. This oxidation amounted to about $3\frac{1}{2}$ per cent. of the weight of the carbides in the case of the 0.36 steel, and to about $2\frac{1}{2}$ per cent. in the 0.50 steel. The carbides were weighed in the crucible after standing for about half an hour in the vacuum desiccator, and it was from these weighings that the above percentages were calculated.

In all cases, except the 0.36 steel, one carbide recovery was sufficient. In this case it was necessary to make two recoveries, using about twenty ampere-hours of current altogether to get sufficient carbides for analysis.

PHYSICAL APPEARANCE.

When viewed under a microscope the carbides appeared to be a very porous, spongy material. They ranged in colour from a very dark grey in cases of the lower carbon steels, to a steel grey in the highest carbon steel. When viewed with the naked eye, the carbides all appeared very similar in physical structure up to the 1.62 steel, which appeared somewhat crystalline. This sample of carbides also seemed to be a little more dense than the others.

MAGNETIC PROPERTIES.

Samples of the carbides were placed on a piece of paper on the stage of a microscope. While viewing the carbides, a magnet was passed back and forth under the stage, and any movement of the

particles was noted. The hypoeutectoid steels and the 0.85 steel gave carbides which were not attracted by the magnet. The hypereutectoid steels gave carbides which were attracted by the magnet, and the higher the carbon content of the steel the more magnetic the mass seemed to be.

COMPOSITION OF CARBIDES RECOVERED.

In the electrolytic recovery of carbides there will always be a certain amount of oxidation accompanied by hydration, the extent of this being dependent on the fineness of division of the carbides themselves and the ease with which the carbides react during the electrolysis. This absorption of oxygen or of water by the carbides during the electrolysis will not, however, influence the atomic ratios between the metals composing the carbides recovered. Duplicate determinations of carbon on all samples were made by combustion, and of chromium, manganese, and iron in the oxides remaining in the platinum combustion boat. These oxides contain no silica, thus indicating that the silicon of the silicides in the steel is oxidised to silicic acid during the electrolysis and passes completely into solution in the electrolyte. The results of the analyses of the carbides recovered are shown in Table II.:

TABLE II.—*Analyses of Carbides.*

Steel.	Carbon.	Chromium.	Manganese.	Iron.	Total per Cent.
0.36	7.38	20.70	0.76	54.02	82.86
0.50	7.73	18.23	0.76	58.92	85.64
0.85	6.73	15.01	0.76	71.18	93.68
1.05	6.81	11.44	0.61	75.33	94.19
1.43	6.82	10.08	0.56	78.44	95.90
1.62	6.65	8.06	0.55	83.11	98.37

COMPUTATION OF DATA TO ATOMIC AND UNIT BASIS.

In order to reduce all results to a uniform basis for comparison, a so-called "unit weight" of steel was adopted. Since, in the series of steels prepared, the concentration of carbon alone was varied, while the relative weights of chromium, manganese, and iron remained constant, the "unit weight" of steel adopted was

that weight of each steel which contained 100 milligramme atoms of chromium, manganese, and iron together. These "unit weights" were computed from the weight per cent. of these elements, as given in Table I.

CALCULATION OF "UNIT WEIGHT."

If the weight per cent. of chromium, manganese, and iron in the original steel is divided by their corresponding atomic weights, the results will give the relative atomic concentrations of the three elements. The relative ratios thus obtained are then reduced to a 100 per cent. basis of the three elements. The atomic ratios thus found in the original steel were : Chromium 2.44, manganese 0.24, and iron 97.32. Multiplying each of these ratios by the atomic weight of the corresponding element in milligrammes gives the weight of each of these elements in one unit of steel. Dividing the sum of these three weights by the sum of the weight per cent. of the three elements in the steel gives the weight of steel necessary to contain 100 milatoms of the three elements. This latter weight has been termed the "unit weight" for each steel.

These values, together with the number of "unit weights" dissolved in the electrolyses, are given in Table III.:

TABLE III.—"Unit Weights."

Steel.	"Unit Weight" of Steel.	"Unit Weights" Dissolved.
0.36	5.624	3.659
0.50	5.632	2.084
0.85	5.652	2.487
1.05	5.663	2.499
1.43	5.685	2.272
1.62	5.696	2.384

In Table IV. are shown the number of milligramme atoms of carbon in one "unit weight" of each of the steels, together with the constant 100 milatoms of accompanying chromium, manganese, and iron. From this table the relative atomic concentrations of chromium to carbon in each of the steels can be readily computed.

TABLE IV.—*Milatoms of Carbon, Chromium, Manganese, and Iron per "Unit Weight" of Steel.*

Steel.	Carbon.	Chromium.	Manganese.	Iron.
0.36	1.687	2.44	0.24	97.32
0.50	2.347	2.44	0.24	97.32
0.85	4.004	2.44	0.24	97.32
1.05	4.955	2.44	0.24	97.32
1.43	6.775	2.44	0.24	97.32
1.62	7.690	2.44	0.24	97.32

In Table V. are given the milligramme atoms of carbon, chromium, manganese, and iron recovered as carbides from one "unit weight" of each steel.

TABLE V.—*Milatoms of Carbon, Chromium, Manganese, and Iron recovered as Carbides per "Unit Weight" of Steel.*

Steel.	Carbon.	Chromium.	Manganese.	Iron.
0.36	0.924	0.598	0.021	1.453
0.50	1.218	0.663	0.026	1.995
0.85	3.137	1.614	0.077	7.129
1.05	3.604	1.397	0.070	8.565
1.43	4.713	1.607	0.085	11.648
1.62	7.679	2.148	0.139	20.623

Table VI. is obtained by subtracting the values given in Table V. from the corresponding ones in Table IV. and, consequently, it shows the number of milatoms of each of the four elements not recovered as carbides.

TABLE VI.—*Milatoms of Carbon, Chromium, Manganese, and Iron not recovered as Carbides per "Unit Weight" of Steel.*

Steel.	Carbon.	Chromium.	Manganese.	Iron.
0.36	0.763	1.84	0.22	95.87
0.50	1.129	1.78	0.21	95.32
0.85	0.867	0.83	0.16	90.19
1.05	1.351	1.04	0.17	88.75
1.43	2.062	0.83	0.15	85.67
1.62	0.011	0.29	0.10	76.70

In Table IV. the milatoms of chromium, manganese, and iron in one "unit weight" of steel are given, being computed in atom

percentages of the three elements, and are constant for all of the steels. In order to get a correct idea of the influence of changes in carbon concentration in the steels on the relative proportion of chromium to manganese to iron in the carbides, the milatoms of each of the three elements recovered as carbides, as shown in Table V., have been computed to a similar basis and expressed in the form of atom percentages of the three metals. These ratios are given in Table VII.:

TABLE VII.—*Atomic Percentages of Chromium, Manganese, Iron, in Carbides recovered.*

Steel.	Chromium per Cent.	Manganese per Cent.	Iron per Cent.
0.36	28.86	1.01	70.13
0.50	24.70	0.97	74.33
0.85	18.30	0.87	80.83
1.05	13.93	0.70	85.37
1.43	12.05	0.64	87.31
1.62	9.37	0.61	90.02

The atomic ratios of chromium, manganese, and iron in both

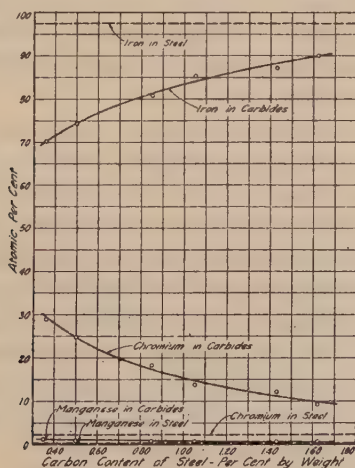


FIG. 3.

steel (Table IV.) and the carbides (Table VII.) are shown graphically in Fig. 3.

DISCUSSION AND SUMMARY OF RESULTS.

1. While, as would be expected, the amount of carbides recovered per "unit weight" of steel dissolved is dependent on the total carbon, the amount of carbon not recovered as carbide is distinctly influenced by the rate of annealing. Steels 0.36, 0.50, 1.05, and 1.43 were "medium" annealed, as defined in the paper referred to on the preparation of these bars, while steels 0.85 and 1.62 were "slowly" annealed—that is, required between two and three times as long a time to cool down from about 950° C. through the critical range. An examination of column 2, Table VI., shows that the milatoms of carbon not recovered are distinctly greater in the "medium" annealed steels than in those which were "slowly" annealed.

2. In order to obtain a comparison of the probable solubility in α -iron of the carbides of a hypoeutectoid chrome steel with those of a very pure carbon steel, carbides were recovered from a 0.45 per cent. carbon bar of such steel. The two steels compared were annealed at the same rate. The carbon not recovered from the pure carbon steel was 0.18 milatom per 100 milatoms of iron, while that not recovered from the 0.50 steel was 1.129 milatoms per 100 milatoms of metal. It will thus be seen that the carbides from the chrome steel are about six times as soluble in α -iron as those from the pure carbon steel.

3. In the 1.62 steel the milatoms of carbon are 7.69 to 2.44 of chromium—that is, the chromium is a little less than one-third the concentration of the carbon. The carbides recovered from this steel appeared very much like those recovered from pure iron-carbon steels, and the insolubility of these carbides would indicate that the amount of chromium was too small to exert much influence on the solubility. When the concentration of chromium exceeds one-third that of the carbon, the effect of chromium becomes more and more marked as the relative concentration of chromium to carbon increases, until it reaches its maximum effect in its two hypoeutectoid steels, 0.50 and 0.36.

4. Although the manganese content of the steel is quite low in the original metal, the tendency of manganese to concentrate in the carbides in a manner similar to that of chromium is clearly shown in Table V., column 4.

5. A study of the curves given in Fig. 3 seems to indicate quite clearly that the laws governing the distribution of chromium between solute and solvent are analogous to those which hold in the formation of mixed crystals, or solid solutions in aqueous solutions or in fused salts.

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Iron and Steel Institute.

NOTES ON THE IRON-NICKEL AND IRON
COBALT EQUILIBRIUM DIAGRAMS.

BY L. GRENET (PARIS).

1. THE KNOWN FACTS

THE iron-nickel diagram is the result of investigations carried out by Osmond, Dumas, and Hanson and Hanson.

It is possible, as a first approximation, to ignore the two-phase region which separates the γ phase region of equilibrium from the α phase region of equilibrium, and to represent the α to γ transformation, on heating, by a single curve, and the γ to α transformation, on cooling, by another curve. By such means the diagram (Fig. 1) is obtained, which is practically the same as that given by Osmond.

The iron-cobalt diagram is the result of observations by Ruer and Kaneko, and, by leaving out the two-phase region between the α and γ states, this diagram presents the appearance of Fig. 2.

Some of the temperatures given by those authors have been slightly amended, in order that the temperatures given for the transformations of pure iron should be the same in all the diagrams.

The transformations α to γ on heating, and of γ to α on cooling, occur at practically the same temperatures. It should be noted, in passing, that the difference between these two diagrams is due mainly to the fact that the cooling transformation of nickel steels differs greatly from the transformation on heating.

If it be desired to plot an equilibrium diagram for iron-nickel, it is logical to take into consideration the fact that the transformation curve on heating approximates closely to the equilibrium curve, but slightly above the latter. Ruer and Kaneko's diagram is to all intents and purposes an equilibrium diagram.

In these two diagrams it will be observed that the line of magnetic transformation (the Curie points) in the γ phase approaches the α to γ transformation curve in the region beyond

which observations are lacking in regard to the nature of the curves. This constitutes a fact which, viewed in the light of the anomalies observed in the dilatation of nickel steels and the

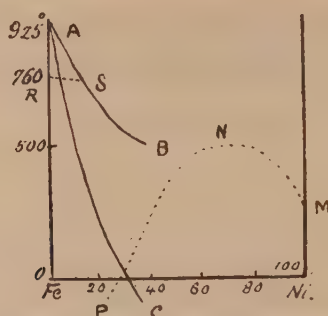


FIG. 1.—Diagram showing Observations made on the Ferro-Nickels.

AB, curve of transformation of α to γ on heating. AC, curve of transformation γ to α on cooling. RS, curve of reversible magnetic transformation of the α phase. PNM, curve of the reversible magnetic transformation of the γ phase.

anomaly in dilatation corresponding with the A2 point in low carbon steels, deserves attention.

If these phenomena be investigated more closely, it will be seen

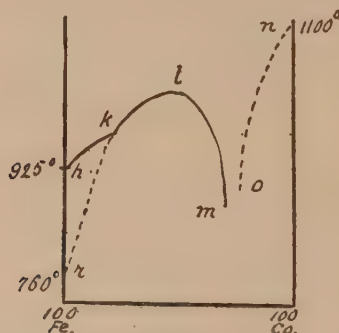
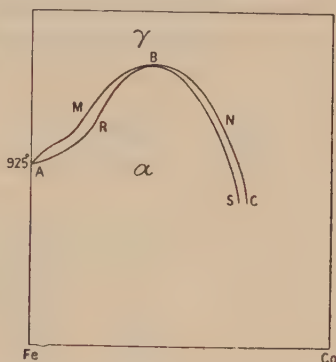
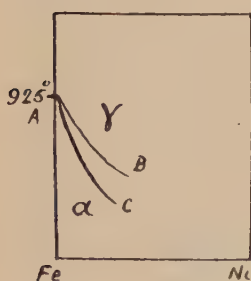


FIG. 2.—Diagram showing the Observations of Ruer and Kaneko on the Iron-Cobalt Alloys.

hkl , curve of the nearly reversible transformation of phase α to phase γ . rk , curve of the reversible magnetic transformation of the α phase. on , curve of the reversible magnetic transformation of the γ phase.

that a two-phase region must separate the two regions α and γ . The existence of this two-phase region, previously inferred from

experimental observations on meteorites, has been definitely established by the investigations of Hanson and Hanson. But although the existence of two phases in equilibrium within a certain temperature range is thus incontestable, it must not be concluded that at the ordinary temperature this two-phase region still exists. The state met with in meteorites may be the result of liquation in a two-phase region consequent on very slow cooling; the copper-tin bronzes with less than 10 per cent. of tin



FIGS. 3 and 4.—Between the curves AB and AC of the ferro-nickel, and in the regions AMBR and CNBS of the ferro-cobalts the α and γ phases co-exist, and are mutually saturated.

often present, at the ordinary temperature, several phases, owing to the liquation corresponding with the passage of a single liquid phase into a single solid phase. It is possible, without departing too far from the observed facts, partially to plot the equilibrium diagrams shown in Figs. 3 and 4.

2. A CONSIDERATION OF THE COMPLETE DIAGRAMS.

If the nickel percentage exceeds 32, or if the cobalt percentage exceeds 75, the known facts no longer justify even the approximate plotting of an equilibrium diagram, and it is necessary, before completing a diagram, to carry experiments further.

A diagram involving the existence of a eutectoid was put forward by Osmond, and has been confirmed by Hanson.

While it becomes increasingly desirable to find a relation

between the magnetic transformation (Curie point) and the transformation accompanying the change of phase α to γ , it appears to the author exceedingly difficult to admit the virtual similarity of these transformations and the existence of a eutectoid of a different character at the juncture of the curves. This remark applies alike to the iron-nickel and iron-cobalt diagrams.

Another solution, which would appear to be perfectly legitimate if amorphous phases were under consideration, would be to admit the existence of "limiting states" between the α and the γ phases, such as the limiting states which exist between the liquid phase

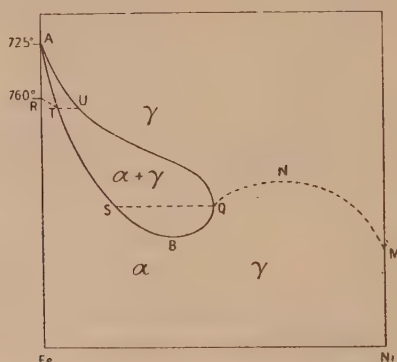


FIG. 5.—Diagram relating to the Existence of Limiting States between the α and γ Phases.

R, point corresponding with a critical temperature and composition. AQB, curve determining the composition of the γ phase saturated with the α phase. BSTA, curve determining the composition of the α phase saturated with the γ phase. RTU and MNQS, curves of the magnetic transformations of the α and γ phases.

and the vapour phase in a mixture of two liquids (at the critical temperatures, pressures, and compositions). At atmospheric pressure a critical temperature of 350° C. and a critical composition of 33 per cent. of nickel might be postulated.

The diagram (Fig. 5) appears capable of grouping the facts in a satisfactory manner, and of explaining the anomalies of dilatation and of density at different temperatures. To this suggestion may be opposed the objection that the continuous passage of the cube-centred α phase to the face-centred γ phase is difficult to conceive.

The separate amorphous states (liquid water and water vapour) may be likened to separate geographical areas divided, in certain

localities, by a precipitous range, whereas, at other localities, they merge into one another by gradual and continuous slopes. On the other hand, distinct crystalline and molecular states may be likened to distinct regions completely isolated from one another by a mountain wall, and in no case merging continuously one into the other.

Is this distinction of too absolute a nature? What is, for the ordinary traveller, an insurmountable barrier, may prove of little impediment to a mountaineer. The question is—can a phase contain several constituent elements of distinct systems?

This raises a delicate problem, in view of the opinion of Benedicks, that the transition from α to γ is continuous, and the investigations of Westgren communicated before the Iron and Steel Institute.¹ The question may be put: "Are there limiting states between the α and the γ phases?"

By way of reply to this question an investigation of the ferro-cobalts, which offer less retardation to transformation than the ferro-nickels, would appear to be of interest.

It may, further, be conceded that a rapid variation in the magnetic properties of a phase corresponds with a rapid variation in the curves of solubility. Whether it be believed that the rapid disappearance of magnetism constitutes a true transformation or not, that disappearance corresponds with an absorption of heat, or with a rapid increase in the calorific power [*pouvoir calorifique*]. The amounts of heat involved in transformations accompanying change of phase vary, therefore, fairly rapidly according to the magnetic state of such phases, and the equilibrium curves will therefore vary according as the magnetic states of the phases vary. In the case of pure iron, the constant diminution in the magnetism remaining at temperatures above 760° is a cause of the diminution in the heat absorbed during the transformation from α to γ when the temperature is raised. This cause may intervene with sufficient intensity for the transformation from α to γ to be, if the temperature be sufficiently high, accompanied by an evolution of heat.

At 1400° C. the transformation α to γ will evolve heat; also, there is observed, on heating, a transformation from γ to δ , which is of the nature of a return to the α , with the absorption of heat.

¹ *Journal of the Iron and Steel Institute*, 1921, No. I. p. 317.

The diagram, Fig. 6, may therefore be accepted in regard to ferro-nickels.

The ferro-cobalt diagram should be analogous.

The existence of anomalous properties may be referred to the fact that, in certain regions of the diagram, the equilibrium between the α and γ phases will vary but little with temperature. Anomalous properties will hence be connected with the existence of a state of equilibrium unaffected by temperature changes.

The variation of the solubility curves may range to the extent of changing the direction of variability of solubility in terms of the

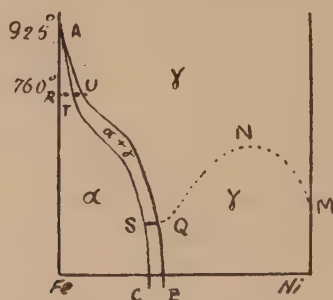


FIG. 6.—Equilibrium Diagram of the Ferro-Nickels, taking into consideration a decided variation in the direction of the equilibrium curves of α and γ , a variation corresponding with the variation of magnetism in the γ phase.

ACB, region of the co-existence in equilibrium of the α and γ phases. RTU, curve of the magnetic transformation of the α phase. MNQS, curve of the magnetic transformation of the γ phase.

temperature. It is thus that it is possible to refer the transformation from phase γ to phase δ (which appears to be the state α) to some such change in the curve connected with the loss of magnetism of the α phase.

If matters be as has been suggested ; if by rapid cooling an equilibrium transformation can be retarded and if, in the sequel, this transformation occurs spontaneously, it will evolve or absorb heat according to the temperature range within which it takes effect.

For this to occur it will be necessary that rapid cooling, although preventing the transformations involving change of phase, shall not prevent modifications of the equilibrium occurring,

compatible with the existence of the phases. Such a condition would appear, not infrequently, very nearly realised in crystals on which the crystalline state confers specific characters and respecting which no transformation is known unless accompanied by change of phase. The magnetic transformation, if the term transformation can be ascribed to it, is exceedingly reversible. The evolution of a phase, from the magnetic point of view, should therefore be more or less independent of the law of cooling. Dr. Guillet has recently described a bronze containing nickel which, after quenching, underwent a transformation with absorption of heat on tempering at about 100°C . It is easy to believe that such a transformation corresponds, not with an equilibrium transformation, but with the destruction of an unstable equilibrium consequent on the quenching.

It is of interest, in this connection, to note that such a bronze can be referred to a diagram relating to magnetic transformations unaccompanied by change of phase (copper-nickel diagram).

3. EXPERIMENTAL ANALOGIES.

(A) Conceive the case of a water thermometer closed by a magnetised rod with its poles as shown in Fig. 7. The pressure of the atmosphere would maintain the magnet in contact with the water. At a certain distance from the rod place a little compass, the needle of which, under the earth's magnetic field, would arrange itself with its north pole towards the magnetised rod. Arrange the system so that, starting with a temperature of 8° , the magnetised rod would be near enough to the compass needle to overcome the terrestrial magnetic field, the positions being as shown in Fig. 7.

If the water were cooled, it would contract and the magnetic rod be drawn further away from the compass needle, so that at 6° equilibrium would be established between the earth's magnetic field and the magnetic field of the magnetised rod. As the cooling continued, the earth's magnetic field would overcome the attraction of the magnetised bar and the needle of the magnet swing round in the inverse direction. The system would have passed from the α state to the γ state.

This cooling transformation, corresponding with a transformation—ii.

tion from a state of stable equilibrium, would be accompanied by an evolution of heat.

On the continuation of the cooling, the magnetised rod would recede still further from the compass; the γ state would remain stable. Then, just below 4° , the water would dilate; the bar would come nearer to the compass, and at 2° a fresh transformation from the stable equilibrium γ to α would occur.

In the neighbourhood of 2° the transformation γ to α would

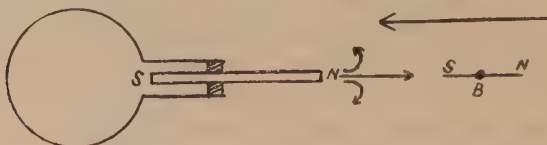


FIG. 7.—Water Thermometer closed by a Magnetised Rod.

When the temperature falls from 8° to 0° the rod first recedes and then again approaches the compass, and the system undergoes two inverse equilibrium transformations, with an evolution of heat.

evolve heat, therefore, and the transformation from α to γ would absorb heat.

α would remain stable as far as 0° , at which point the experiment can be regarded as ended.

Assume, now, that on cooling to just below 6° the unstable α equilibrium be maintained. If, subsequently, the transformation α to γ takes place suddenly, it will do so with an evolution of heat in the neighbourhood of 6° , at 5.5° , for example, and with an absorption of heat in the neighbourhood of 2° , for example, 2.5° . Finally, the unstable equilibrium α , if it be maintained till below 2° , will become stable by the suppression of two inverse transformations.

(B) Let it be assumed that at above 1400° the δ phase is the same as the α phase (Curie, Westgren, and Phragmén).

The transformations on cooling are thus δ (or α) to γ , with evolution of heat at 1400° , and γ to α with evolution of heat at 925° .

It may be conceived that a sufficiently energetic quenching (realisable perhaps in the case of alloys other than pure iron) might permit of the observation of the following phenomena :

Quenching from 1450° to 1350° with the observation, after quenching, of a spontaneous transformation of δ or α into γ , with evolution of heat.

Quenching from 1450° to 1200° , with the observation of a spontaneous transformation of δ or α into γ , with neither evolution nor absorption of heat.

Quenching from 1450° to 950° , with the observation, after quenching, of a spontaneous transformation of δ or α into γ , with absorption of heat.

Quenching from 1450° to a temperature below 925° , with the retention of the δ or α state as the stable form.

4. CONCLUSIONS.

The author has conceived it of interest to record these suggestions more with the view of showing how the question of the relation between magnetic transformation, and transformation accompanied by change of phase, may be regarded than as the expression of a formal opinion on the subject.

The study of the ferro-cobalts should be simpler than that of the ferro-nickels. The comparative study of these two categories of alloys should therefore enable the problems presented by the investigation of the ferro-nickel alloys to be solved, and might, moreover, throw a light on the nature of the A2 point in mild steels.

CORRESPONDENCE.

Professor CECIL H. DESCH, F.R.S. (Member of Council), wrote that Mr. Grenet appeared to have paid insufficient attention to the work of Benedicks on the synthesis of meteoric irons in 1910-11. Benedicks obtained structures in alloys containing a large percentage of nickel which were best interpreted as representing a eutectoid. The microscopic observations of Hanson and Hanson were in accordance with the same view, and the diagram given by Hanson and Freeman was consistent with all the known facts, allowing for the great temperature lag in the transformations which was characteristic of those alloys, and for the slow diffusion which was observed in most alloys containing nickel. It did not seem possible to accept such a diagram as that suggested in Fig. 5 for an entirely crystalline system. The gradual transition from γ to α was not easily reconciled with modern views as to the structure of crystals, and the difficulties which led Benedicks to assume a special form of allotropy could be explained in a simpler manner. On the other hand, it was quite possible that the δ and α regions might meet when the proportion of nickel exceeded a certain amount, the γ region being then bounded by a closed curve, as had been suggested with much probability by Oberhoffer for the iron-silicon alloys. The magnetic analogy so ingeniously devised and applied by Mr. Grenet depended on the anomalous properties of water in the neighbourhood of its freezing point, and there was nothing to show that it had a parallel in the iron alloys. On the whole, while admiring the ingenuity of Mr. Grenet's suggestions, he considered that the equilibrium diagram proposed by Hanson and his colleagues accounted for most of the facts, and that if modifications should be needed in the future it would not be necessary to abandon the eutectoid or to introduce conceptions which were foreign to the usual representation of metallic systems.

Mr. L. GRENET replied as follows :

It is much to be regretted that my imperfect knowledge of the English language prevents me from understanding the full meaning of the publications, and I shall re-read in particular that of Benedicks, as suggested by Professor Desch. In contradistinction to many of my compatriots I begin to believe more and more in a fairly strict relation between the anomalies of properties of a phase and the transformation with change of phase, but I cannot yet admit the possibility of including on one diagram, and denoting by a single name, the transformation with change of phase, and the transformation without change of phase, as has been done by Hanson and Freeman.

I agree there is justification for Professor Desch's criticisms of Fig. 5, but one must not be too dogmatic and look upon a crystal as only a space lattice of atoms. The bond between the atoms in a molecule is perhaps gradually diminished as crystalline organisation is developed, but is not ruptured suddenly. The difference between the specific heat as found and that which one would deduce from the atomic composition, and the anomalies of properties without change of phase are very interesting to study from this point of view. Neither must one neglect the analogies which may often be observed between anomalies of the crystalline phases and those of the amorphous phases in the neighbourhood of the critical regions.

Definition of "Phase."—The term "phase" is synonymous with "a mass" or "a crowd."

The idea of homogeneity of a mass is independent of the dimension of the individuals, simple or complex, which are being considered (cells, men, regiments, atoms, molecules). A collection of distinct elements is a phase; when those distinct elements are individuals having definite and limited dimensions. Identical elements can thus subsist without tendency to absorb one another. In this phase or mass there is equilibrium between the individuals. A collection of distinct elements, even though homogeneous, is an aggregate, when these elements, though they may be extremely small, have no individuality, and their dimensions are not definite and when they tend to agglomerate in order to form a smaller number of distinct collections and are only prevented from so doing by frictional resistances.

So far in chemical systems we recognise as individuals only the atom and the molecule. A crystal is a mass, an organised mass, having a certain individuality, but of indefinite dimensions. Elements of identical crystal form do not subsist together in equilibrium but tend to absorb one another.

The questions: Do limited crystalline phases exist? and: Is diagram No. 5 acceptable? may be combined into one query: Do crystalline individuals actually exist?

The question as to the acceptance of Fig. 5 has already been raised by Bain's experiments, which showed that copper and manganese had different space lattices; are they to be included in one phase, as is indicated by micrographic examinations? In my opinion the answer to these questions is "No," but this negative is not sufficiently absolute to warrant a refusal to examine these questions further.

Anomalies of Solubility.—I admit that diagram No. 6 is the one which appears to me most probable; it raises the question of the relation between all the anomalies postulated in the properties of a phase (magnetic anomalies of steels and the anomalies noted by Chevenard in the α phase of the brasses) and the solubility curves relating to that phase.

At a time when I refused point-blank to apply the term "transformation" to magnetic anomalies of the α phase we (Charpy and

Grenet) drew an equilibrium diagram of the α and γ phases, which might be interpreted as showing an anomaly of solubility. More recent experiments carried out with an improved apparatus by Seibei-Konno¹ do not show this anomaly as related to the "Curie" point of the α phase. That is a point which still requires confirmation.

It has been shown how much the weakening of the character of the transformation of the α into the γ phase in the silicon steels appears abnormal, and an attempt has been made to unite the α and δ phases in one diagram by introducing a variation of solubility connected with the Curie point of the α phase.² In considering the known facts concerning the ferro-silicons and the ferro-cobalts³ and a transformation and absorption of heat during cooling of a nickel-brass (Dr. Guillet), it appears logical to admit an inversion of the solubility curves as connected with the magnetic state of the phases present.⁴ Duhem had also indicated the possibility of a similar inversion.⁵

Up till then I had been inclined to connect the junction of the phases α and δ of the silicon or aluminium steels with the complete elimination of the carbon of the α phase. I have since learned that Oberhoffer has admitted an analogous curve to connect the phases α and δ of silicon steels. I do not know yet whether that author connects that form of curve with the magnetic condition of the phases present. In putting forward a mechanical example showing a spontaneous change of state with absorption of heat on cooling, I simply wished to justify the possible inversion of the solubility curves, and did not intend to establish a special analogy with the transformations of the ferro-nickels.

Summary.—Three diagrams deserve consideration. The diagram of Hanson and Freeman, the diagram No. 5, and the diagram No. 6, which latter appears to me the only acceptable one.

The examination of these three diagrams raises certain questions. The study of the relation between the anomalies of properties without change of phase and the laws of solubility of various alloys, and particularly the ferro-cobalts, appears likely to shed considerable light on the equilibrium diagram of the ferro-nickels.

¹ *Revue de Métallurgie, Extraits*, 1924, vol. xxi. p. 126.

² *Technique Moderne*, 1921; *Comptes Rendus*, 1922.

³ Sansfourche, *Revue de Métallurgie, Mémoires*, 1919, vol. xvi. p. 217; Ruer et Kanéko, *Revue de Métallurgie, Extraits*, 1916, vol. xiii. p. 77.

⁴ *Revue de Métallurgie*, August 1925, vol. xxii.

⁵ "Thermodynamique et Chimie," edited by Hermann, p. 205.

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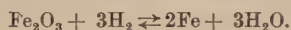
REDUCTION OF FERRIC OXIDE AND IRON ORES BY HYDROGEN.

By HEIHACHI KAMURA, M.Sc.
(MEIJI COLLEGE OF TECHNOLOGY, TOBATA, JAPAN).

INTRODUCTION.

HYDROGEN, like carbon monoxide, is a very strong reducing agent in regard to metallic oxides. If hydrogen be passed over iron oxides at a moderate temperature, the iron will be obtained in the metallic state with the formation of H_2O .

On the other hand, if a current of water vapour be passed over heated metallic iron, oxide of iron will be formed and hydrogen evolved. This reaction was proved by Deville to be reversible, and is shown by the following chemical equation:



There is a certain proportion of H_2O in equilibrium at different temperatures, and the amount has been determined by several investigators. The reaction does not proceed in either direction when the tension of the oxygen in the iron oxide and in the H_2O is the same.

In the present investigation the object was not to determine the equilibrium condition, but to estimate the reduction velocity at different temperatures.

CHEMICAL EQUILIBRIUM OF IRON OXIDE AND HYDROGEN.

The chemical equilibrium of $Fe-O_2-H_2$ and $FeO-H_2$ has been determined by several authors. Lavoisier's work on the composition of water showed that steam reacts with Fe at $150^\circ C.$, liberating H_2 and forming Fe_3O_4 :



In this equilibrium the very early work of Deville¹ is the model for all later investigators. Preuner² worked by the same

¹ Deville, *Comptes Rendus*, 1870, vol. lxx. pp. 1105, 1201; 1871, vol. lxx. p. 30.

² Preuner, *Zeitschrift für physikalische Chemie*, 1904, vol. xlvii. p. 385.

method of experiment as Deville, which was to measure the total pressure developed when water vapour from a reservoir of liquid water, kept at constant temperature, was allowed to react with metallic iron at a series of temperatures between 150° and 1200° C. Both workers assumed their reactions to correspond with equation (1), and their results are shown in Table I.

TABLE I.

Temp. in Degrees.	K.	Percentage of H_2 .
200	0.0491	95.32
265	0.0688	93.56
360	0.1188	89.39
440	0.1758	85.06
770	0.5410	64.94
920	0.6590	60.23
900	0.687	59.27
1025	0.781	56.18
1150	0.860	53.76

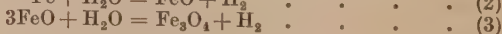
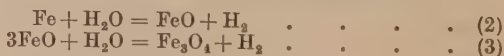
Deville

Preuner

Later, the same equilibrium system was investigated by Chaudron,¹ Wöhler,² Schreiner and Grimmes.³ In his latest paper Chaudron states that ferrous oxide prepared at a high temperature reacts on cooling partly according to the equation—



and it has been pointed out it is possible that, in the temperature range below 570° , ferro-ferric oxide may actually be the oxide in equilibrium with iron. Chaudron found the triple point at which Fe, FeO, and Fe_3O_4 coexist to be 570° C. Above 570° C. the equilibrium curve has two branches corresponding with



Below 570° C. one system only can exist :



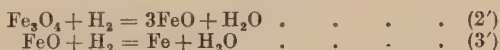
¹ Chaudron, *Comptes Rendus*, 1914, vol. cliv. p. 273.

² Wöhler, *Zeitschrift für Elektrochemie*, vol. xxiii. p. 199.

³ Schreiner and Grimmes, *Zeitschrift für anorganische Chemie*, 1920, vol. cx. p. 311.

It may therefore be adequate to consider that the equilibrium corresponds with the equation (1) below 570° , but it is undoubtedly incorrect to regard it as occurring at the higher temperature.

Eastman¹ summarised the results which had been determined by the above-mentioned investigators, and attempted to draw a curve representative of the results, but failed to find any concordance between them. Lately, he has determined the composition of the gas phase in the system $\text{Fe-H}_2\text{-O}_2$, with the solid phase varying in average composition between pure Fe and Fe_3O_4 . The results indicate the existence of a solid solution at this temperature, in the composition range 0 to 5 per cent. O_2 , 20 to 24 per cent. O_2 , and above about 27 per cent. O_2 . He has also determined equilibrium constants in the divariant equilibrium in this system represented by the equations, between 657° and 1025°C. :



In his opinion the best values of these equilibrium constants obtained by different observers are shown in Table II.

The constants, $\text{H}_2\text{O}/\text{H}_2$ given for the reactions, are designated K_2 , K_3 for the reactions (2') and (3') respectively.

TABLE II.—*Equilibrium Constants* $(\text{H}_2\text{O})/(\text{H}_2)$.

Temperature . . .	700°	750°	800°	850°	900°	950°	1000°
$\text{FeO-Fe}_3\text{O}_4$ system, K_2	1.45	2.11	2.98	4.16	5.50	7.08	9.12
Fe-FeO system, K_3	0.584	0.645	0.706	0.765	0.822	0.879	0.937

The values of K_2 and K_3 are shown graphically in Fig. 1. Curves 2 and 3 in the figure are drawn from the logarithms of K_2 and K_3 in the table respectively, against the reciprocals of absolute temperatures. Their extrapolations to lower temperatures intersect at about 570°C. This is the transition temperature below which ferrous oxide is unstable with respect to ferro-ferric

¹ E. D. Eastman, *Journal of the Chemical Society*, 1922, vol. xliv. p. 975; 1924, vol. xlvi. p. 888.

oxide and iron. Curve 1 in the figure is that calculated for the constants in the reaction :



The curves in Fig. 2 show the composition of gaseous phase in the above three equilibriums at different temperatures. It is

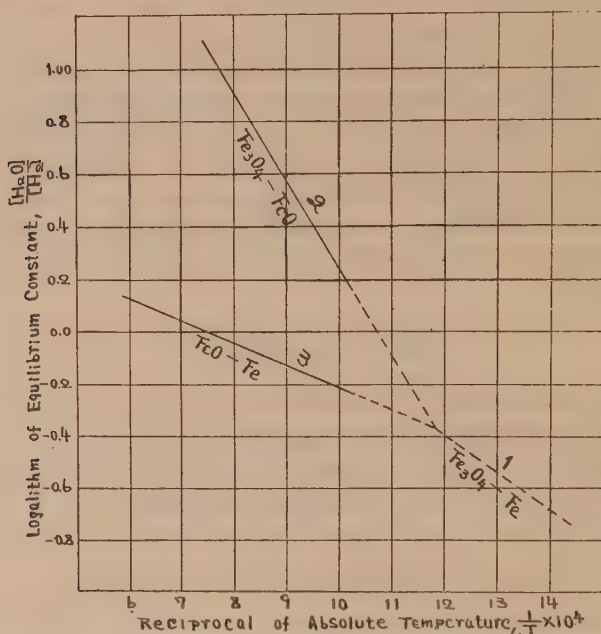


FIG. 1.—Equilibrium Constants and Temperature in the System
 $\text{Fe} - \text{H}_2 - \text{O}_2$.

possible to find the composition of the gaseous phase at any temperature from these curves.

TEMPERATURE OF REDUCTION OF IRON OXIDE TO METALLIC IRON BY HYDROGEN.

At what temperature can the iron oxide be reduced to the metallic state by hydrogen? No reliable data has been observed. It is said that iron oxide can be reduced slowly to the metallic state even at 200°C . According to Friend's "Inorganic Chemistry," vol. ix., Part II., ferric oxide reduced to Fe_3O_4 at 330°C . ;

from Fe_3O_4 to FeO at 500°C .; and from FeO to metallic iron at 600°C . The reduction has been observed to commence at about 305°C . with magnetic oxide, and at 370°C . with ferrous oxide.

The data available differ according to different authors, but it seems from the equilibrium curves in Fig. 2 that the reduction of ferro-ferric oxide to metallic iron will commence a little above

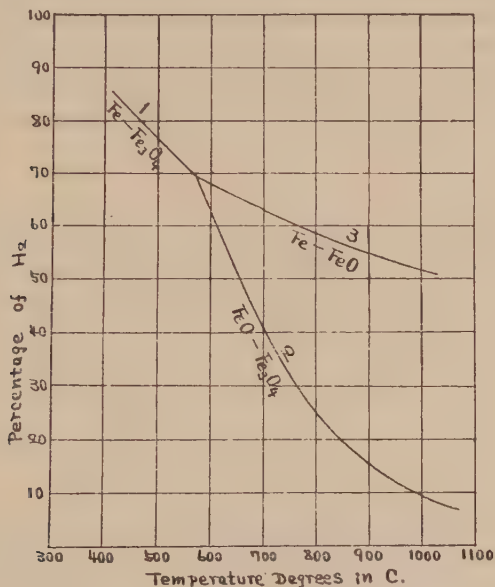


FIG. 2.—Chemical Equilibrium Curves.

- (1) $\text{Fe}_3\text{O}_4 + 4\text{H}_2 \rightleftharpoons 3\text{Fe} + 4\text{H}_2\text{O}$
- (2) $\text{Fe}_3\text{O}_4 + \text{H}_2 \rightleftharpoons 3\text{FeO} + \text{H}_2\text{O}$
- (3) $\text{FeO} + \text{H}_2 \rightleftharpoons \text{Fe} + \text{H}_2\text{O}$

300°C ., and that above 570°C . either the reduction of Fe_3O_4 to FeO or of FeO to metallic iron will commence, according to the equilibrium conditions prevailing.

ARRANGEMENT OF EXPERIMENT.

In Fig. 3, A is a Kipp's apparatus for producing hydrogen, and E is an electric-resistance furnace made of nichrome wire. The reduction experiment is carried out on a sample which is placed in an alundum boat in the combustion tube F in the furnace. G is a U-tube filled with calcium chloride.

When the desired temperature is obtained in the furnace, the inside of the combustion tube is evacuated by the mercury bottle K, and the hydrogen produced in A is passed into the combustion tube. The hydrogen gas from A, which may contain some water vapour, passes through B, and the moisture is absorbed by H_2SO_4 . The water vapour produced by the reduction passes into G with the stream of hydrogen and is absorbed by CaCl_2 . By ascertaining the increased weight of G, the exact amount of H_2O produced by the reduction can be determined. The volume of hydrogen which does not take part in the reduction is measured by an aspirator H. A bottle containing concentrated H_2SO_4

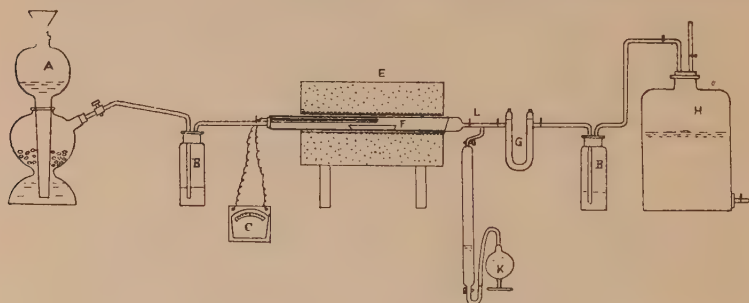


FIG. 3.—Arrangement for Experiment.

is placed between G and H to prevent the absorption of humidity in the aspirator by the CaCl_2 in G. The glass tube L on the left side of the combustion tube is heated by a water-bath continuously during the experiment to prevent the condensation of H_2O on the inside of the tube. The temperature in the combustion tube is measured by a platinum-platinum rhodium thermocouple.

REDUCTION OF FERRIC OXIDE.

Preparation of Ferric Oxide.

The ferric oxide produced in nature as iron ore contains some impurities which may be affected by the hydrogen during the reduction. Pure ferric oxide was therefore taken for the experiment to avoid the influence of such impurities. To make the pure ferric oxide, a pure ferric chloride solution was prepared and iron hydroxide precipitated by ammonium hydroxide. The washed

precipitate of $\text{Fe}_2(\text{OH})_6$ was dried and ignited at 700°C . Analysis of the oxide showed 69·9 per cent. of iron content, so that it was understood that nearly all the iron existed in the state of Fe_2O_3 .

One gramme of ferric oxide is placed in the boat in the combustion tube. Hydrogen from A is passed into the combustion tube at a velocity of from 30 to 40 cubic centimetres per minute.

The weight of the calcium chloride tube is measured at intervals of ten to fifteen minutes. The progress of reduction is known by its increased weight, and when no further increase of weight occurs, reduction has evidently ceased. The operation is then interrupted, and the stoppers at the two ends of the combustion tube closed. The weight of reduced iron is measured after the furnace has cooled.

One gramme of Fe_2O_3 contains 0·3 gramme of oxygen, so that it requires 416 cubic centimetres of hydrogen to secure perfect reduction; but a certain equilibrium exists in the reaction, as previously stated—that is, certain proportions of H_2 and H_2O , which correspond with the equilibrium at a given temperature, will exist in the gas after reduction. The volume of hydrogen to be used will therefore be much larger than what is theoretically required, and will vary according to the temperature of reduction.

RESULTS OF THE EXPERIMENTS.

The reduction was carried out at three different temperatures— 500° , 600° , and 700°C . The results obtained are shown in the following tables :

A. No. of Experiment, 28. Temperature of Reduction, 500°C .

Time after Reduction Started.	Volume of H_2 Passed.	Weight of H_2O Formed.	Weight of O_2 Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	348	0·0582	0·0517	17·2
25	789	0·1222	0·1086	36·2
40	1213	0·1761	0·1565	52·2
55	1654	0·2262	0·2012	67·1
70	2086	0·2700	0·2400	80·0
85	2497	0·3042	0·2702	90·1
100	2869	0·3221	0·2862	95·4
115	3247	0·3249	0·2927	97·6
130	3642	0·3309	0·2940	98·0
145	4018	0·3346	0·2972	99·1

Weight of sample after reduction, 0·7055 gramme.

B. *No. of Experiment, 31. Temperature of Reduction, 600° C.*

Time after Reduction Started.	Volume of H ₂ Passed.	Weight of H ₂ O Formed.	Weight of O ₂ Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	423	0.1107	0.0985	33.6
25	934	0.2109	0.1875	64.1
40	1384	0.2849	0.2532	86.5
55	1818	0.3233	0.2872	98.1
70	2210	0.3270	0.2906	99.3
85	2590	0.3291	0.2925	100.0

Weight of sample after reduction, 0.6994 gramme.

C. *No. of Experiment, 29. Temperature of Reduction, 700° C.*

Time after Reduction Started.	Volume of H ₂ Passed.	Weight of H ₂ O Formed.	Weight of O ₂ Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	594	0.1825	0.1622	54.1
25	1052	0.2784	0.2476	82.5
40	1498	0.3269	0.2906	96.9
55	1906	0.3369	0.2995	99.8

Weight of sample after reduction, 0.6938 gramme.

From the results of the experiments it can be seen that the percentage of reduction obtained was 99 per cent. at 500° C., with a time of reduction of two hours and twenty-five minutes and a hydrogen rate of 27.2 cubic centimetres per minute. In experiments No. 31 and No. 29 nearly perfect reduction was obtained, with volumes 30.4 and 27.2 cubic centimetres of hydrogen per minute respectively. In No. 31 the time required for reduction was one hour twenty-five minutes, and in No. 29 one hour ten minutes. The volume of hydrogen passed in the three cases was 4018 cubic centimetres, 2590 cubic centimetres, and 1906 cubic centimetres. The higher the temperature of reduction the less the volume of gas required. This means a value of $H_2O/H_2 = K$ in equilibrium condition increases, and the velocity of reduction increases as the temperature of reduction becomes higher.

In Fig. 4 the curves show the rate of reduction at each temperature, taking the volume of the hydrogen as abscissæ and the percentage of reduction as ordinates. It may be considered that the comparison of the rate of reduction at different velocities of hydrogen is not adequate. It was, however, quite impossible

to keep the gas current constant by the arrangement adopted in this experiment. It was assumed from the experiments that the reaction to attain a certain equilibrium condition or a certain proportion of H_2 and H_2O at a different temperature did not take as much time as was expected. There was not much difference in the volume of gas required for the reduction in different velocities of the gas at the same temperature of reduction. This means that the reaction reaches a definite equilibrium very quickly. The dimensions of the combustion tube used in the experiment were 20 millimetres inside diameter,

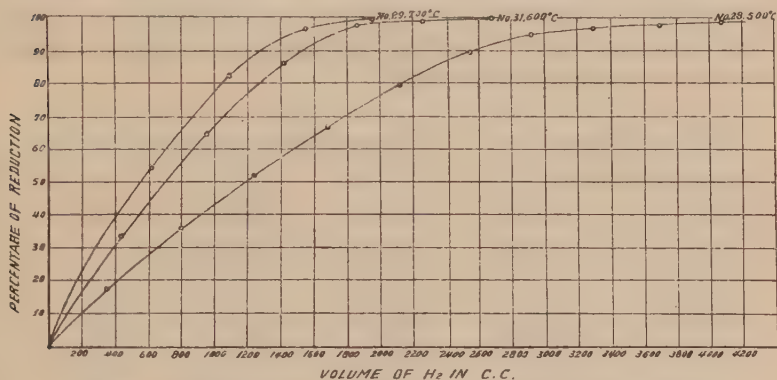


FIG. 4.—Rate of Reduction on Ferric Oxide by Hydrogen.

and the length 40 centimetres. Therefore its internal capacity was 126 cubic centimetres. The time required for passing the gas from one end to the other was two minutes at a temperature of reduction $500^{\circ}C.$, when the velocity of gas was 30 cubic centimetres per minute.

REDUCTION OF HÆMATITE.

In the previous experiments the reduction was made on pure ferric oxide. The same experiment was subsequently carried out on hæmatite ore. The ore used was a very dense and rich hæmatite from China. The size was from 20 to 30 mesh per linear inch, and the analysis was as follows :

Ignition Loss.	Total Fe.	Fe as Fe_2O_3 .	Fe as Fe_3O_4 .	SiO_2 .	Al_2O_3 .
1.29	64.929	64.179	0.75	6.0	0.94
CaO.	Mn.	MgO.	P.	S	
0.432	1.428	0.116	0.039	trace	

The percentage of oxygen combined with iron was 27.791 per cent.

The same arrangement was used for this experiment as in the previous case. One gramme of hæmatite was taken in the boat, and the reduction was effected at seven different temperatures—namely, 500°, 550°, 600°, 650°, 700°, 750°, and 800° C.

The velocity of the hydrogen was kept as constant as possible, but it was very difficult to do so, as the pressure in the Kipp's apparatus varied all the time. The hydrogen was passed at from 30 to 35 cubic centimetres per minute. The weight of H_2O formed by the reduction was measured by the increased weight of $CaCl_2$ in the U-tube. The results obtained at each temperature are shown in the following tables :

D. No. of Experiment, 19. Temperature of Reduction, 500° C.

Time after Reduction Started	Volume of H_2 Passed.	Weight of H_2O Formed.	Weight of O_2 Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	431	0.0462	0.0411	14.4
25	939	0.1005	0.0894	32.2
40	1453	0.1594	0.1420	51.1
55	1960	0.2206	0.1962	70.6
70	2450	0.2601	0.2312	83.2
85	2952	0.2939	0.2613	94.0
100	3412	0.3015	0.2680	96.4
115	3829	0.3045	0.2707	97.4
130	4222	0.3046	0.2708	97.5

Weight of sample after reduction, 0.7227 gramme.

E. No. of Experiment, 23. Temperature of Reduction, 550° C.

Time after Reduction Started.	Volume of H_2 Passed.	Weight of H_2O Formed.	Weight of O_2 Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	393	0.0850	0.0755	26.6
25	893	0.1483	0.1320	46.5
40	1427	0.2156	0.1917	67.6
55	1952	0.2837	0.2520	88.8
70	2422	0.3069	0.2730	96.3
85	2861	0.3124	0.2780	98.0
100	3298	0.3169	0.2818	99.3
115	3731	0.3182	0.2828	99.7

Weight of sample after reduction, 0.7208 gramme.

F. No. of Experiment, 22. Temperature of Reduction, 600° C.

Time after Reduction Started.	Volume of H ₂ Passed.	Weight of H ₂ O Formed.	Weight of O ₂ Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	451	0·0979	0·0868	32·7
25	1072	0·1954	0·1753	65·5
40	1556	0·2575	0·2288	86·4
55	2018	0·2826	0·2512	94·7
70	2449	0·2904	0·2583	97·5
85	2879	0·2935	0·2610	98·5
100	3298	0·2958	0·2628	99·2
115	3607	0·2978	0·2646	99·8

Weight of sample after reduction, 0·7207 gramme.

The curves shown in Figs. 5, 6, and 7 are rates of reduction at 500°, 550°, and 600° C. respectively, taking the volumes of

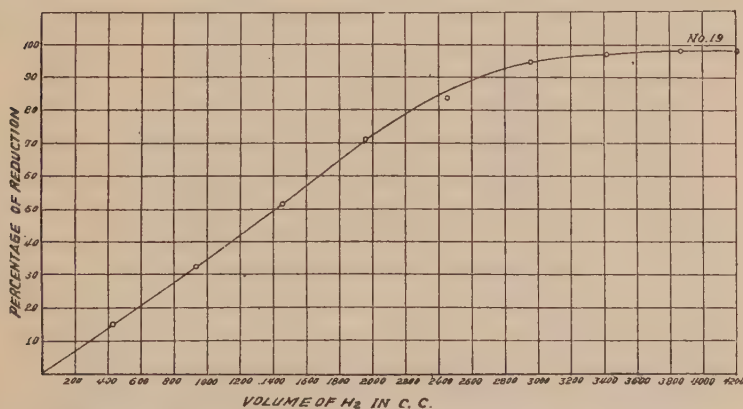


FIG. 5.—Rate of Reduction on Hæmatite by Hydrogen at 500° C.

hydrogen as abscissæ and the percentages of reduction as ordinates. The weight of O₂ combined with iron in 1 gramme of the ore is 0·2779 gramme, and when all the iron is oxidised to the state of FeO the weight of oxygen will become 0·1855 gramme. Unless, therefore, the weight of oxygen combined with iron in the ore became less than 0·1855 gramme, no iron would be obtained in the metallic state.

The percentage of reduction is calculated by the diminished weight of the sample after reduction, assuming the rest of the

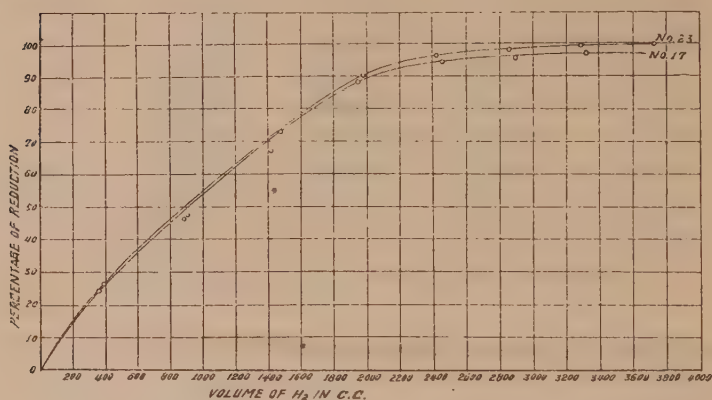


FIG. 6.—Rate of Reduction on Hæmatite by Hydrogen at 550° C.

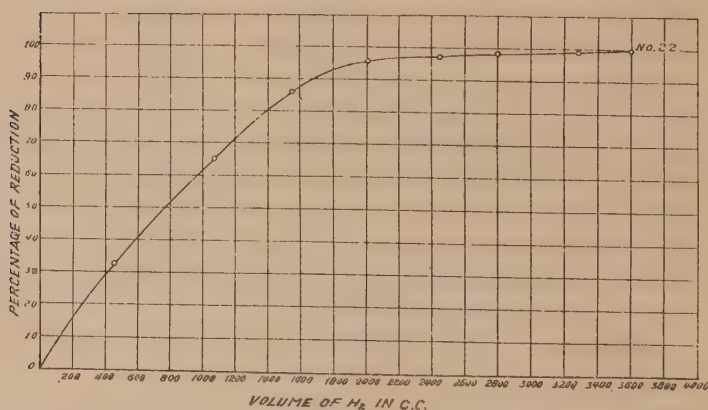


FIG. 7.—Rate of Reduction on Hæmatite by Hydrogen at 600° C.

O₂ to be combined with iron as FeO. When the weight of diminution exceeded the weight of O₂ combined by calculation with iron, the percentage of reduction was regarded as 100 per cent.

G. No. of Experiment, 21. Temperature of Reduction, 650° C.

Time after Reduction Started.	Volume of H ₂ Passed.	Weight of H ₂ O Formed.	Weight of O ₂ Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	451	0·0979	0·0868	32·7
25	1072	0·1954	0·1735	65·5
40	1556	0·2575	0·2288	86·4
55	2018	0·2826	0·2512	94·7
70	2449	0·2904	0·2583	97·5
85	2879	0·2935	0·2610	98·5
100	3298	0·2958	0·2628	99·2
115	3607	0·2978	0·2646	99·8

Weight of sample after reduction, 0·7208 gramme.

No. of Experiment, 20. Temperature of Reduction, 650° C.

Time after Reduction Started.	Volume of H ₂ Passed.	Weight of H ₂ O Formed.	Weight of O ₂ Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	436	0·1000	0·0889	32·3
25	1026	0·2013	0·1790	65·0
40	1548	0·2780	0·2470	90·1
55	2007	0·2966	0·2640	96·0
70	2461	0·3034	0·2695	98·0
85	2903	0·3073	0·2735	99·5
100	3342	0·3092	0·2748	100·0

Weight of sample after reduction, 0·7154 gramme.

H. No. of Experiment, 13. Temperature of Reduction, 700° C.

Time after Reduction Started.	Volume of H ₂ Passed.	Weight of H ₂ O Formed.	Weight of O ₂ Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	426	0·1141	0·1018	36·6
25	977	0·2137	0·1899	68·3
40	1523	0·2858	0·2540	91·5
55	1957	0·2990	0·2650	95·6
70	2400	0·3040	0·2703	97·3
85	2860	0·3071	0·2730	98·2
100	3292	0·3100	0·2755	99·1
115	3721	0·3111	0·2764	99·5
130	4201	0·3116	0·2768	99·7

Weight of sample after reduction, 0·7206 gramme.

I. *No. of Experiment, 15. Temperature of Reduction, 750° C.*

Time after Reduction Started.	Volume of H ₂ Passed.	Weight of H ₂ O Formed.	Weight of O ₂ Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	379	0·1125	0·1001	34·8
25	1016	0·2475	0·2200	76·6
40	1491	0·2988	0·2660	92·6
55	1976	0·3113	0·2768	96·5
70	2408	0·3190	0·2838	98·9
85	2842	0·3226	0·2868	100·0

Weight of sample after reduction, 0·7143 gramme.

J. *No. of Experiment, 16. Temperature of Reduction, 800° C.*

Time after Reduction Started.	Volume of H ₂ Passed.	Weight of H ₂ O Formed.	Weight of O ₂ Reduced.	Percentage of Reduction.
Minutes.	Cubic centimetres.	Gramme.	Gramme.	
10	525	0·1557	0·1384	48·8
25	1077	0·2717	0·2416	85·4
40	1592	0·3106	0·2761	97·5
55	2018	0·3165	0·2812	99·3
70	2439	0·3184	0·2830	100·0

Weight of sample after reduction, 0·6978 gramme.

The rate of reduction in 650°, 700°, 750°, and 800° C. is shown by the curves in Figs. 8, 9, 10, and 11. It will be seen that the velocity of reduction increases distinctly as the temperature becomes higher.

RATE OF REDUCTION AT DIFFERENT TEMPERATURES.

The experimental results obtained at the seven different temperatures are shown in the table on p. 293. All the experiments were carried out on a 1 gramme sample.

The rate of reduction at different temperatures is compared by the curves in Fig. 12. At 500° C. the reduction was nearly finished when 4200 cubic centimetres of hydrogen had passed at a rate of 32 to 35 cubic centimetres per minute. At 550° C. and 600° C. the velocity of reduction increased considerably, and finally at 800° C. the reduction was completed in one hour only by a volume of hydrogen 2400 cubic centimetres.

Generally, the reduction takes place very rapidly at first, and becomes slower as the oxygen in the solid phase decreases. After 90 per cent. of oxygen in the original sample has been taken off,

No. of Experiment.	Temperature of Reduction.	Time required for Reduction.	Total Volume of H_2 Passed.	Velocity of H_2 Passed per Min.	Weight of H_2O Formed.	Percentage of Reduction.		
						From the Weight of H_2O .	From the Weight of reduced Fe.	By Analysis.
	° C.	Minutes.	C.c.	C.c.	Gramme.			
19	500	120	4227	35.2	0.3046	97.5	98.6	90.7
17	550	100	3327	33.3	0.2899	92.1	97.0	91.2
23	550	115	3731	32.4	0.3182	100.0	99.7	90.4
22	600	115	3607	31.4	0.2978	95.2	99.8	90.2
20	650	100	3342	33.4	0.3092	98.9	102.5	92.3
21	650	85	2921	34.4	0.3189	100.0	101.0	92.0
12	700	115	2869	25.0	0.3010	96.3	93.1	88.0
13	750	130	4201	32.3	0.3116	99.7	99.8	91.6
14	750	85	2972	35.0	0.3409	100.0	102.4	93.1
15	750	85	2842	33.4	0.3226	100.0	103.1	93.5
16	800	70	2439	34.8	0.3184	100.0	...	95.1

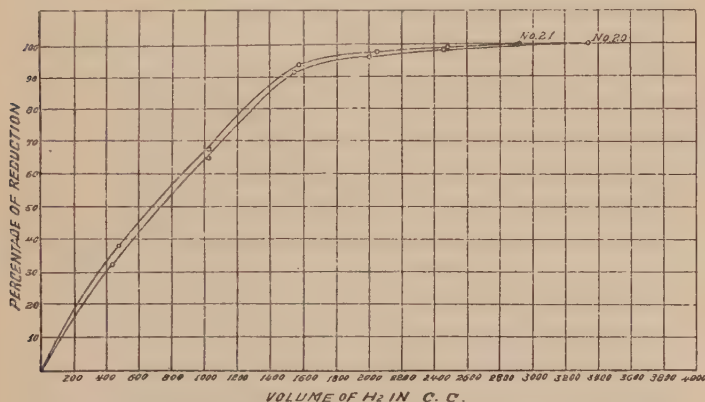


FIG. 8.—Rate of Reduction on Hematite by Hydrogen at 650° C.

the further reduction progresses very slowly. In Fig. 13 the velocity of reduction is compared at four different temperatures, 500°, 600°, 700°, and 800° C.; the velocity of the gas remains about the same in each case. At 500° C. the time required was seventy-eight minutes to get 90 per cent. reduction, but only forty-six minutes at 600° C. The times were thirty-nine and thirty minutes at 700° and 800° C. respectively.

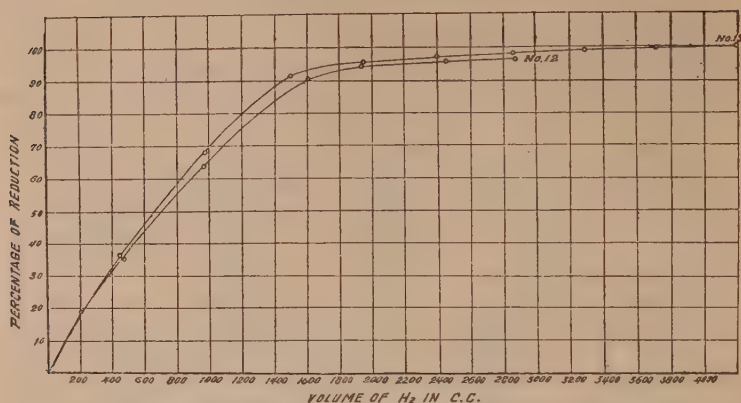


FIG. 9.—Rate of Reduction on Hematite by Hydrogen at 700° C.

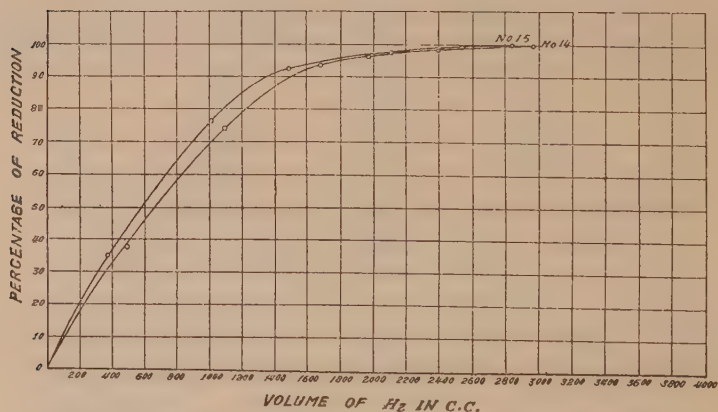


FIG. 10.—Rate of Reduction on Hematite by Hydrogen at 750° C.

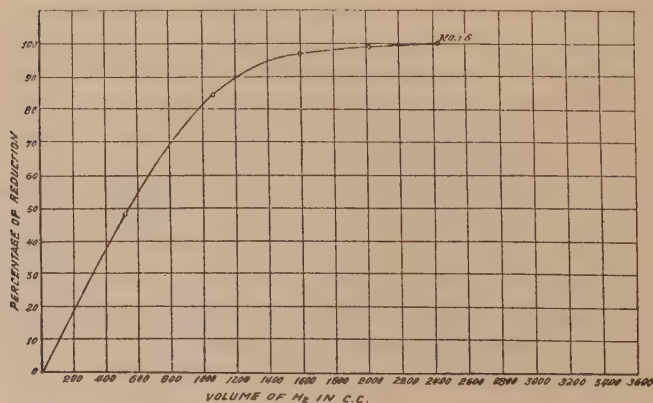


FIG. 11.—Rate of Reduction on Hematite by Hydrogen at 800° C.

RELATION BETWEEN THE TEMPERATURE OF REDUCTION AND THE VOLUME OF HYDROGEN USED.

The velocity of reduction increases as the temperature increases. This means the higher the temperature the more the

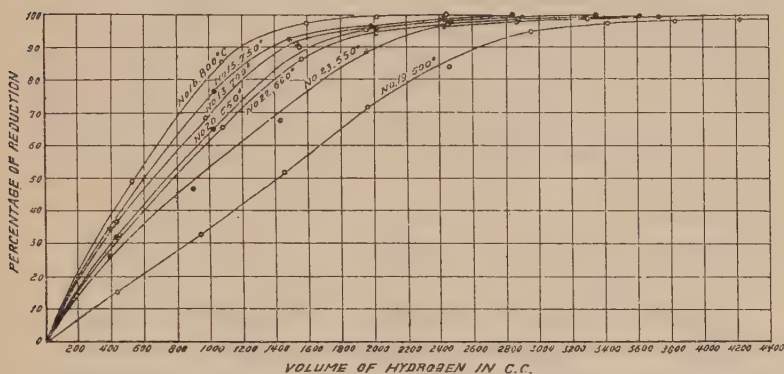


FIG. 12.—Rate of Reduction on Hämatite by Hydrogen at Different Temperatures.

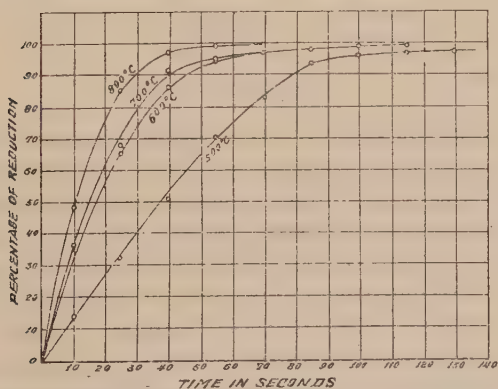
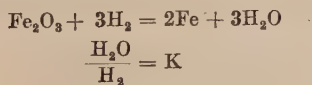


FIG. 13.—Reduction Velocity on Hämatite by Hydrogen.

equilibrium constant K increases in the following chemical equilibrium :



This tendency is in fairly good agreement with the actual equilibrium constant K in previous tables, in which it rises as the temperature increases. But in this experiment the hydrogen for the reduction passes through the tube continuously, so that the true equilibrium cannot be established, but only the equilibrium which can be reached in a definite time of contact between the iron oxide and the hydrogen. Now, the total volume of H_2 required to reduce the iron oxide is X , and the total volume of H_2O produced is Y . Therefore, in the equation $Y/X = K$ the value of Y is nearly constant, and X will diminish as the temperature becomes higher, so that K will be raised as calculated in the following table :

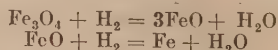
Temperature of Reduction.	X.	Weight of H_2O Formed.	Y.	K.
° C.	Cubic centimetres.	Grammes.	Cubic centimetres.	
500	4227	3046	376	0.089
550	3731	3132	393	0.105
600	3323	3012	372	0.112
650	3126	3026	386	0.123
700	2869	3010	372	0.130
750	2842	3226	398	0.140
800	2439	3184	393	0.161

CONCLUSION.

It will be understood by the results obtained that nearly perfect reduction can be effected at $500^\circ C.$ in about two hours, the hydrogen passing at 35 cubic centimetres per minute. With a higher temperature of reduction the time required will be shorter and the volume of hydrogen will be less. At a temperature of $600^\circ C.$ the velocity of reduction increases rapidly and the volume of hydrogen used decreases suddenly. This is probably due to the appearance of the solid phase FeO , which could not exist under $570^\circ C.$, according to the equilibrium curves ; that is to say, under $570^\circ C.$ the reduction takes place as follows :



Above this temperature it may be considered as taking place in two stages :



Above 600°C . the velocity of reduction does not increase as it does around this temperature, and the volume of hydrogen used does not make much difference, so this will be the most economic temperature for the reduction of iron ores by hydrogen.

In some of the results the weight of oxygen obtained as H_2O is in excess of the weight of oxygen combined with iron. This is probably due to experimental error. There is a discrepancy between the percentage of reduction calculated from the weight of reduced iron and that from its analysis. Some of the percentages of reduction from the weight of reduced iron are much higher than 100 per cent. There is some doubt as to the cause, but it may be explained as follows :

1. The constituent of the ore is not chemically uniform, and as the size of ore taken for analysis is 20 to 30 mesh per linear inch, there may be some difference between the composition of the sample used for the experiment and the average analysis.

2. The reduction of oxides of impurities in the ore like SiO_2 , MnO , &c., may account for the difference ; as regards the influence of the silica, reduction was attempted at 750°C . by hydrogen with pure SiO_2 , but no change could be found. The influence on MnO and on other oxides has not been investigated.

The estimation of metallic iron in reduced samples was made by displacing the Hg in HgCl_2 by metallic iron, and the amount of iron in chloride solution was determined by the ordinary volumetric method.

The reduced iron is very oxidisable in the atmosphere even during the sampling. The percentage of reduction found by analysis will always be somewhat lower, therefore, than the real results.

ACKNOWLEDGMENT.

This experiment was carried out in the metallurgical laboratory of Meiji College of Technology. The author wishes to express his appreciation of the facilities granted by the Faculty of the College.

CORRESPONDENCE.

Mr. RALPH C. V. WHITFIELD (Redcar) wrote that he thought the author would agree that, in its commercial aspect, the cost of production of hydrogen on a scale sufficiently large would be found so high as to render any process based upon the $\text{Fe}_2\text{O}_3 - \text{H}_2$ interaction practically prohibitive.

Except for a record of the experiments made some years ago in Toronto, Canada (in which hydrogen was successfully used following its production as a by-product in certain processes), he knew of no literature in which the explicit statement was made that hydrogen could be utilised as a prime reducing agent, and it appeared that the general opinion as to its value in that respect was somewhat obscure.

Bell, in his "Manufacture of Iron and Steel," 1884, stated that in no case in his exhaustive investigations into the phenomena of blast-furnace reactions had he found that hydrogen effected any pronounced reduction of the iron oxide of the charge, but apparently he maintained an open mind on that question.

Whilst the production of practically pure hydrogen was an expensive matter, the production of gases carrying appreciable amounts of hydrogen from industrial fuels was comparatively easy.

Quite recently, by the use of pulverised bituminous fuel, a gas had been produced containing under 0.5 per cent. CO_2 , and consisting essentially of 32 per cent. CO , 14 per cent. H_2 , 52.5 per cent. N_2 , and he would suggest that the author gave some consideration to the question of the reducing effect of that gas, and particularly that of the contained hydrogen, upon an iron ore running 35 per cent. of iron as ferric oxide, in a temperature region of from 700° to 1000°C .

There was no argument as to the reducibility of iron oxide by heated CO , though opinions differed as to the completeness of the reaction within the temperature limits above defined, and it was quite possible that hydrogen, if present in the amount given, would have an important influence upon the CO reaction by ensuring its completeness. If the author would investigate the problem in that direction, his deductions would add much to the value of his paper, as he (Mr. Whitfield) was very strongly of the opinion that only along those lines would the solution of the question of direct reduction of iron ore be found.

Iron and Steel Institute.

RETAINED AUSTENITE.

BY JOHN A. MATHEWS, PH.D., SC.D. (NEW YORK).

THE retention of austenite, or gamma-iron, at ordinary temperatures is frequently mentioned in metallurgical literature, but it seems that little effort has been made to determine the exact causes or conditions under which its presence may be expected, or to measure its amount or its effects upon the properties of steel and steel alloys when variable amounts of alpha- and gamma-iron are present. In the author's opinion it is present much more frequently than it is generally supposed to be, and in substantial amounts.

Many text-books on metallography instruct the beginner how to prepare a specimen to show austenite. He is usually told to secure a sample of very high-carbon steel—1.50 per cent. or higher—and a high manganese content is no objection. Such a sample he is told to heat to 2000° F. and quench in iced brine. Upon polishing and etching, he sees not austenite, but a mixture of austenite and martensite. From this early introduction to the austenitic structure the beginner acquires a lasting impression that austenite is a rare constituent in ordinary steel, and possibly it is in readily visible amounts at the ordinary magnifications.

In some recent investigations the author has reached conclusions so contrary to those generally accepted that it seemed desirable to submit them to the Iron and Steel Institute, together with the evidence upon which they are based. These conclusions may be summarised as follows :

1. In all normally hardened medium or high carbon steels, and in the usual engineering alloy steels, gamma-iron or austenite is always present with the martensite. This conclusion is based upon the nature of the volume changes which occur upon tempering hardened steels. There first occurs a contraction, due to the tempering of martensite and the precipitation of submicroscopic carbides ; later, by tempering at higher temperatures, an expansion occurs, due to the transformation of austenite. The work of

Howard Scott,⁽¹⁾ M. A. Grossman,⁽²⁾ Heindelhofer and Wright,⁽³⁾ and others, illustrates this phenomenon and confirms the reasonableness of this view. The recent paper by B. D. Enlund⁽⁷⁾ fully confirms this and extends it to fairly low carbon steels.

2. In a wide variety of alloy steels, notably those capable of hardening readily in oil, there is more austenite retained after the oil quench than after the water quench in normal hardening. Experiments to be described later will make clear the reason for this conclusion.

3. Retained austenite is a contributing cause to increased permanence or retentivity in permanent magnet steels and in many alloy steels not used for permanent magnets.

This conclusion may seem strange when it is remembered that gamma-iron is, in itself, non-magnetic. In that capacity its influence is to reduce the maximum induction of the steel containing it, and at saturation it may be that the difference is roughly proportional to the quantity present. It not only cuts down the maximum induction at saturation, but it also makes both magnetising and demagnetising more difficult. It is not merely an inert dilutant of the alpha-iron.

The nature of the newly discovered cobalt magnet steels seems to confirm this conclusion. They contain from 15 to 35 per cent. of cobalt, in addition to 5 to 10 per cent. of the ordinary constituents of permanent magnet steel—tungsten, molybdenum, chromium, and manganese. Such steels have marked austenitic characteristics, and some of them by overheating may become almost non-magnetic. One such steel, after quenching from 1900° F., showed only 375 gaussses of residual magnetism instead of the customary 9000 to 11,000 gaussses of good magnet steel. When quenched from 2000° F. it was still less magnetic, and for a magnetising field of $H = 750$ it gave maximum induction of 2190, residual induction of 160, and coercive force (H_c) of 65. This sample showed a purely austenitic structure with carbides, but after immersion in liquid air the structure was greatly changed and a mixture of austenite, martensite, and carbides appeared, and the magnetic properties were greatly increased—the residual density increased from 160 to 1500 gaussses, and the coercive force from 65 to 81.5. The increase in coercive force may appear contrary to the author's third conclusion, but if the ratio of coercive

force to residual magnetism be considered it will be seen to have increased—that is, the steel after liquid air treatment is lower in inherent permanency than before. The use of the expression “coercive force” implies that something has been “coerced” by the “force,” and that is a certain amount of residual magnetism; therefore, the ratio Br/Hc gives a truer measure of inherent magnetic stability than the Hc value alone.

Photomicrographs were made for the author by Mr. Francis F. Lucas,⁽⁴⁾ whose work upon high-power metallography has attracted wide attention. They are taken at 3230 magnification, and illustrate the effect of liquid air on the overheated steel referred to. Plate XXVI. shows the cobalt steel as hardened; Plate XXVII. shows the same steel after liquid air treatment.

It is interesting to observe that the second treatment in liquid air of the overheated cobalt magnet steel did not produce a further material change, yet the material after this treatment is far from being normal in its magnetic properties. Just why the transformation does not complete itself is difficult to explain. Furthermore, normally treated material of the same composition is not very greatly affected by the liquid-air treatment, since the Br values only increased from 8160 to 8580, while the coercive force (Hc) dropped from 166 to 158.4, these changes respectively being plus 5.1 per cent. and minus 4.6 per cent.

Mr. Howard Scott⁽¹⁾ showed that hardened high-speed steel undergoes a similar change upon treatment with liquid air—that is, the maximum and residual induction are increased, while the coercive force is decreased; and the amount of the change is greater the higher the hardening temperature—that is, the greater the amount of austenite present. Conversely, the author has found the coercive force to increase very rapidly for ascending hardening temperatures of high-speed steel, and maximum values are attained by hardening at about 2400° F., where the development of the austenite is greatest.

It should be recalled that cobalt magnet steels excel only in high coercive force (Hc), and not in superior maximum or residual magnetism. Table I. gives a few results for comparison of residual magnetism (Br) and coercive force (Hc) for typical cobalt, tungsten, and chromium magnet steels, which illustrate this point.

TABLE I.

	H.	Br.	Hc.
Cobalt, No. 1	1500	10,100	237
„ „ 2	750	8,850	155
„ „ 3	750	7,890	193
Tungsten, No. 1	300	10,300	71
„ „ 2	300	10,700	66.5
Chromium, No. 1 (water)	300	10,710	60.0
„ „ 2 (oil)	300	8,540	64.5

The comparison would have been better had the magnetising field H been constant, but the value was sufficiently high in all cases to approach saturation values. It will be observed that the residual magnetism of cobalt No. 1 is not higher than that of the tungsten steels, or than the chromium steel hardened in water, but that the coercive forces are from three to four times as great and, in the author's opinion, this is due to the influence of retained austenite.

In 1914 the author ⁽⁵⁾ called attention to the fact observed in one of his laboratories that a large class of alloy steels shows greater magnetic hardness when quenched in oil than when quenched in water. The general belief at that time was that the harder a given steel could be made the lower would be its induction and the higher its retentivity. By magnetic hardness is meant high coercive force. This was tested out for a wide variety

TABLE II.

C.	Si.	Mn.	Cr.	Ni.	V.
0.61	0.54	0.82	0.80	...	...
0.50	0.51	0.79	0.73	...	...
0.24	0.21	0.46	0.96	2.02	...
0.25	0.21	0.74	...	3.55	...
0.30	0.19	0.64	...	3.25	0.18
0.47	1.83	0.70	...	...	...
0.90	0.30	0.35	2.00	...	...

of alloys, as shown in Table II., and for all these steels it was found that, as quenched in oil, they showed a lower Brinell or Shore hardness than when quenched in water, yet in all cases the coercive

force was higher in oil than in water ; that is, the oil-quenched samples were more resistant to magnetising and more permanent after magnetising.

It is natural to think of the effect of oil hardening as being somewhat equivalent to a water hardening followed by a greater or less degree of tempering. There is some justification for this view when the resulting mechanical properties are considered. Steels could be made of the same elastic limit or Brinell hardness by such methods, but magnetically and structurally the results are not the same. Fig. 1 illustrates the difference. The descending

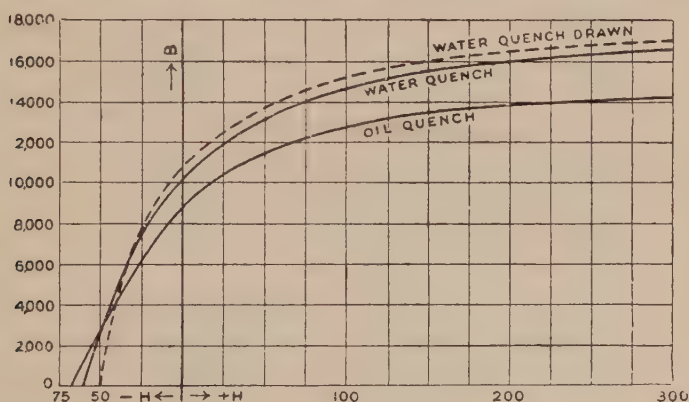


FIG. 1.

position of the magnetising curves of a steel similar to the last one in Table II. are shown. In heavy lines are shown the differences between oil and water quenching—a lower maximum induction, residual induction, and a higher coercive force are seen to result from oil quenching. The dotted curve shows what happens when a water-hardened steel is mildly tempered ; the induction is raised and the coercive force is lowered. This is directly opposed to the effect of oil hardening.

At the time this anomalous behaviour of oil hardening was announced no attempt at explanation was made, and, indeed, no explanation has been offered in the intervening years, so the problem was taken up again, and the conclusions given at the beginning of this paper were reached after the following tests had been made.

A comparison between the changes of length upon tempering and the magnetic changes induced by that tempering was made with two steels of the following analyses :

	M31.	M62.
Carbon	0.84	0.91
Silicon	0.20	0.25
Manganese	0.47	0.34
Chromium	2.96	2.16

Test specimens $\frac{1}{2}$ inch round were prepared and hardened from a temperature of 1525° F., one set in oil and one set in water

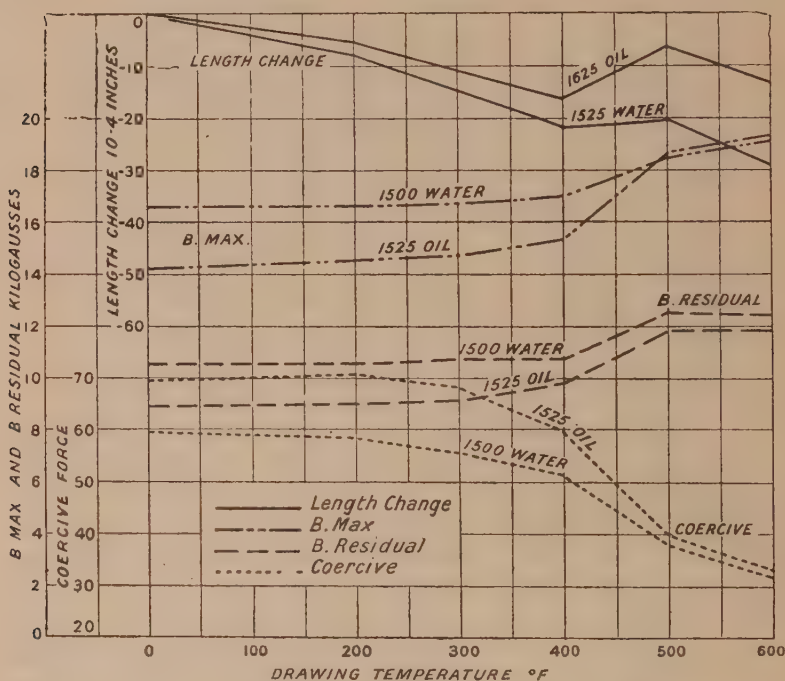
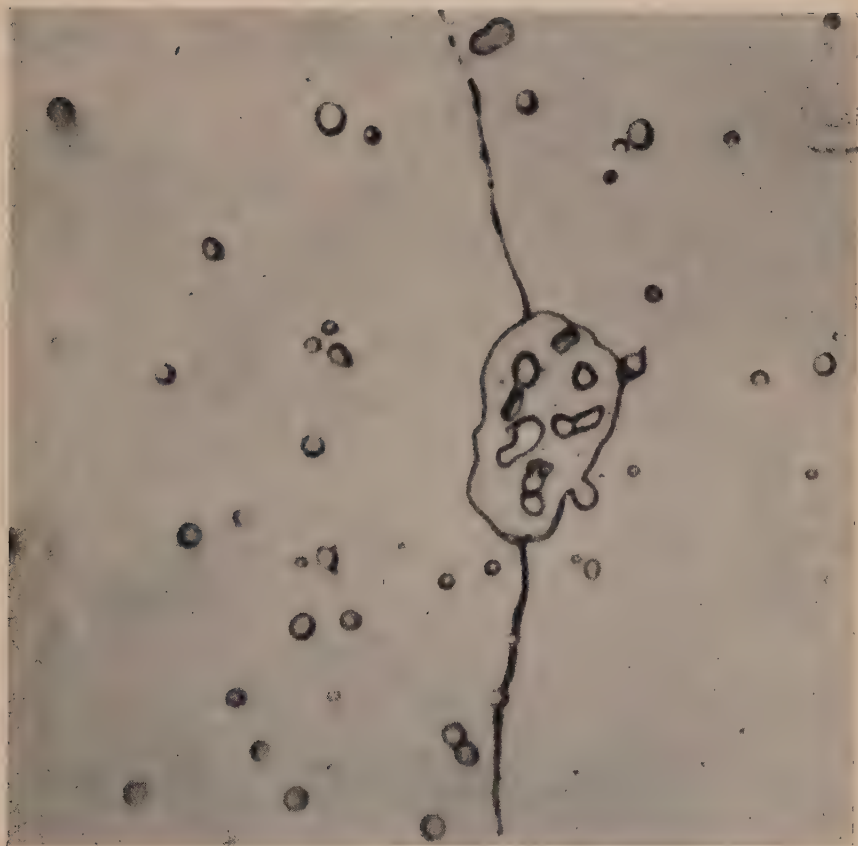


FIG. 2.

for both steels. These were then tempered at 100° F. intervals from 200° to 600° F., holding at heat for half an hour. The two steels behaved similarly, and results of one of them only need be given, namely M31, as shown in Fig. 2.

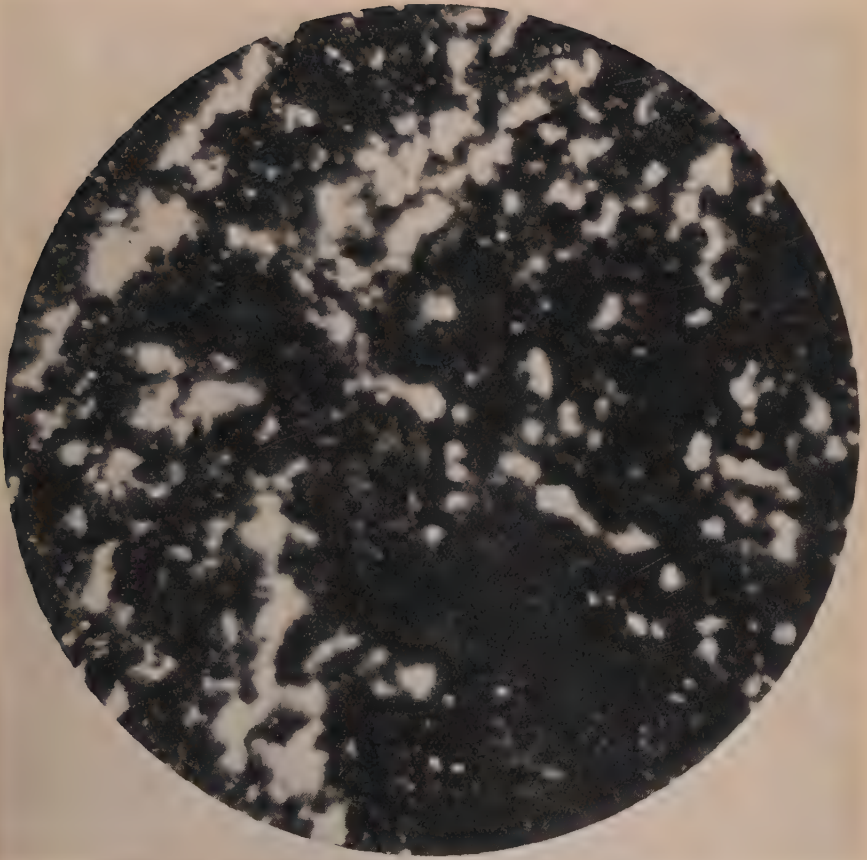
The striking similarity between length changes and magnetic changes is at once apparent. The shrinkage which first takes



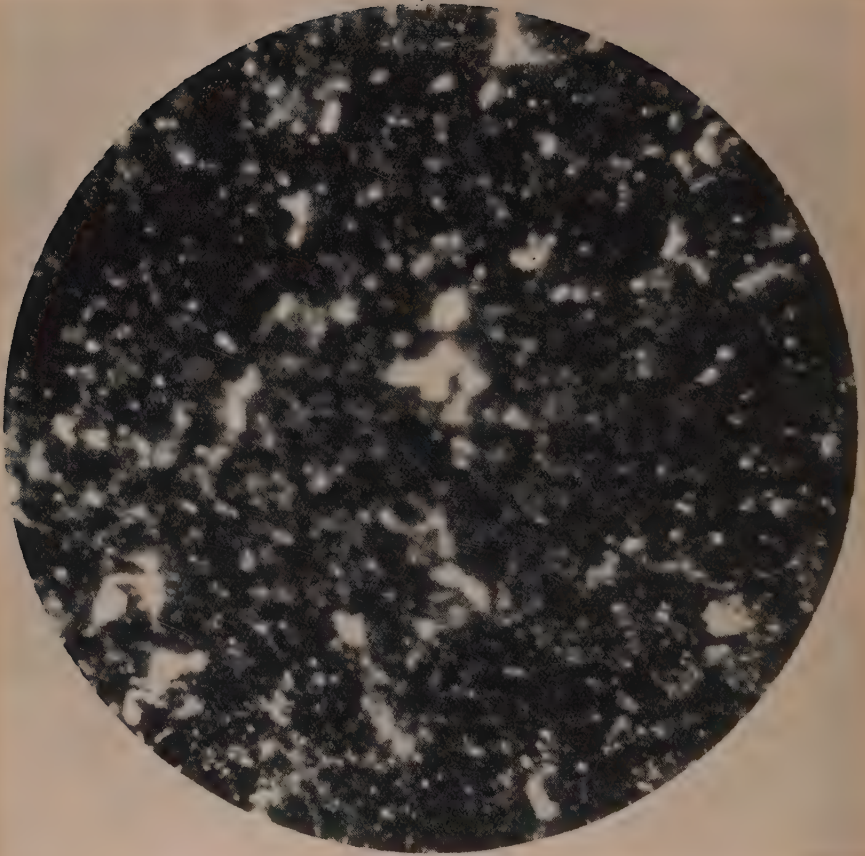
Cobalt magnet steel hardened in oil from 2000° F. $\times 3230$.



Cobalt magnet steel hardened in oil from 2000°F. and chilled 1 hour in liquid air.
×3230.



M—31. Oil hardened from 1525°F. Sodium picrate etch. $\times 2830$.



M—31. Water hardened from 1525°F. Sodium Picrate etch. $\times 2830$.

place is due to the tempering of martensite with the precipitation of carbides. The expansion begins when austenite is transformed to martensite. It will be noted that the shrinkage is greatest in the water-hardened piece, while expansion is greatest for the oil-hardened specimen, suggesting varying proportions of martensite and austenite resulting from the methods of quenching. The magnetic properties follow the length changes very closely, and the greater slope of the "oil" line between 400° and 500° is followed by a greater slope for increase of maximum induction ($B_{\max.}$), residual induction (Br), and decrease of coercive force (H_c).

It is known that hardened steel is lighter than annealed steel ; in fact, martensite is the lightest, that is, the most voluminous condition of steel. A hardening which produces the lowest specific gravity (greatest volume) may be considered as the most complete martenisation possible for that steel. A hardened steel of greater specific gravity (smaller volume) must indicate retained austenite or that the hardening has gone beyond the martensite stage toward troostite or pearlite. In order to check this point, specific gravity determinations were made not only on the two steels referred to above but on several others, as shown below, and in every instance the water hardening produced the lower specific gravity, indicating more martensite, while the higher density in oil was, the author believes, due to gamma-iron :

Steel.	Oil Quenched.	Water Quenched.
M-62 No. 1	7.8548	7.8416
M-62 „ 2	7.7996	7.7861
M-31	7.8371	7.8302
5 per cent. tungsten	8.1292	8.1015
2 per cent. Cr, 1 per cent. Ni .	7.8255	7.8177
2 per cent. Cr, 1 per cent. W .	7.8755	7.8580

These figures suggest retained austenite due to oil quenching, but probably there is gamma-iron, or austenite, present in all cases, although in varying degree, as the expansion curve in Fig. 2 indicates. It should not be assumed that 400° F. is a fixed temperature for all steels, for we need only recall that the austenite-martensite transformation begins at about 1000° F. in hardened high-speed steel.

Not only a retarded rate of cooling due to quenching in oil, but also a retarded cooling due to the cross-section or size of the test-

piece results in lower induction and increased retentivity. This was pointed out by the author many years ago, but the experiment was repeated recently with a different sample, a different testing method, and a different observer; but in this matter of size it is found that increased size, both as water and oil quenched, makes for increased magnetic hardness. This again is opposed to the idea that the harder one can make a given steel and the more drastically one can cool it, the less permeable and the more permanent it will become. From a single bar of $\frac{3}{4}$ inch steel test-pieces of $\frac{3}{8}$ inch, $\frac{1}{2}$ inch, and $\frac{1}{16}$ inch respectively were made, one set being hardened in oil and one in water from a temperature of 1525° F. The steel used contained 0.81 per cent. carbon and 2.91 per cent. chromium. The magnetic properties are shown in Table III.

TABLE III.—*Effect of Size on Magnetic Properties.*

Diameter.	1525° F. in Oil.			1525° F. in Water.		
	3/8 Inch.	1/2 Inch.	11/16 Inch.	3/8 Inch.	1/2 Inch.	11/16 Inch.
B _{max.} (H = 300) . . .	15,400	15,400	13,600	16,600	16,600	15,500
B _{res.}	9,650	9,380	8,780	10,600	10,400	10,300
Hc	60.3	62.2	66.0	55.2	58.1	58.8
Br/Hc	160	151	133	192	179	175

In producing the austenite-martensite transformation by tempering, some tempering of the martensite already present must also be produced, but it was believed that this change might be produced by immersion in liquid air without disturbing the martensite. Accordingly, the six test-pieces of Table III. were immersed for two hours, and after several days were retested, with very interesting results. The oil-hardened bars, suspected of having an increasing amount of austenite as the size increased, were found to have increased in residual magnetism (Br) by 6, 8, and 14 per cent. from small to large, while the coercive force (Hc) had decreased 1, 2, and 7 per cent. respectively. The water-hardened bars were but little changed, 1 to 2 per cent. in residual magnetism and 2 per cent. in coercive force, but the coercive force increased instead of decreased, as in the other case. This seems fairly con-

clusive evidence in support of the influence of austenite on the permanence or retentivity of magnetism.

Through the generous co-operation of two metallurgists, Mr. Edgar C. Bain and Mr. Francis F. Lucas, it is possible for the author to add some confirmatory evidence along lines in which these gentlemen are experts. They received portions of identical samples upon which magnetic tests had been made.

Mr. Bain, after X-ray examination, reports faint lines corresponding with the gamma-iron pattern in both steels for both oil and water quenching. A further test warranted him in stating that it is fairly clear that the oil-hardened specimen shows more gamma-iron than the water-hardened specimen. The indications are that the amount of gamma-iron in either case is not very great, perhaps 6 to 10 per cent.

Mr. Lucas examined both steels under high-power magnification. Ordinary magnifications are of little use in studying these extremely fine-grained steels. At 3000 diameters, and with nitric acid etching, no great differences could be detected between water- and oil-quenched specimens, but upon boiling in sodium picrate the martensite and carbides darkened, leaving numerous uncoloured areas, believed to be austenite. Several pictures were taken of each steel as oil or water quenched, and it was quite readily possible to separate these into two groups, based upon the quantity of the white constituent, austenite, which is plainly more pronounced in the oil-quenched condition. The photomicrographs shown in Plates XXVIII. and XXIX. illustrate the difference in appearance of the M-31 steel as oil and water quenched.

In the presentation of this subject, the author has drawn upon and amplified a portion of the Henry Marion Howe Memorial Lecture,⁽⁶⁾ which it was his privilege to deliver in February last before the American Institute of Mining and Metallurgical Engineers. Some results obtained even later have been added. It would seem that the confirmation afforded by the work of Mr. Bain and Mr. Lucas justifies the conclusions stated at the beginning, and a new viewpoint as to the nature of the hardening process must result, which may prove of interest and value in interpreting various phenomena met with in daily work. These new concepts offer a logical explanation of the magnetic anomalies to which the author first called attention in 1914, for which no other explana-

tion has ever been made. It is obvious that in answering these questions another question is raised—why does oil hardening retain more gamma-iron than water hardening in a considerable variety of steels? It is believed that a more intensive investigation of quenching stresses rather than of quenching rates may afford an explanation. May it not be that this is an important function of the commoner alloys—chromium and manganese, and their mixtures with nickel, vanadium, molybdenum, and others to promote the retention of austenite, and that to this fact is due some of the properties of alloy steels as compared with carbon steels?

In conclusion, the author wishes to acknowledge his indebtedness to Mr. Peskowitz, who carried out most of the heat treatments and magnetic tests under his direction, and also to Mr. Edgar C. Bain and Mr. Francis F. Lucas for their kindly co-operation in confirming the experiments by other methods.

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CORRESPONDENCE.

Mr. J. FERDINAND KAYSER (Sheffield) wrote that as the author so frequently referred to magnetic data, it was unfortunate that the expressions "permanence," "retentivity," "coercive force," &c., had been so misused.

In conclusion 3, "permanence" and "retentivity" were apparently used to describe one and the same property. Then, later, it was incorrectly stated that the use of the expression "coercive force" implied that something had been "coerced by the force." Hopkinson first gave the terms "coercive force" and "retentivity" a real meaning by defining "retentivity" as the residual or remanent magnetism which persisted when a magnetising force was removed from a long bar or closed ring of the material under consideration, and "coercive force" or "coercivity" as being equal and opposite to the demagnetising force required to destroy that residual magnetism. "Permanence" was unfortunately a property which was not at all understood even at the present day. All authorities were, however, agreed that neither "retentivity" nor "coercive force" gave any indication of the permanence of a magnet.

From his (Mr. Kayser's) experience with all types of cobalt magnet steels, he could not agree that retained austenite was "a contributing cause to increased permanence or retentivity in permanent magnet steels." The author rightly remarked that some of the cobalt steels had marked austenitic characteristics, and that some of them by over-heating might become non-magnetic. If, however, he examined steels of a similar composition, but containing no cobalt, he would find that their austenitic characteristics were precisely the same, but they would not possess the high coercive force characteristic of a cobalt steel.

He (Mr. Kayser) thought that the above was quite sufficient to show that the author's third conclusion was incorrect, and experiments with high-speed steels also showed that his theory was quite untenable. The author's contention that the coercive force of a high-speed steel increased very rapidly for ascending hardening temperatures, and that it was a maximum when the development of the austenite was greatest, was quite correct when referring to samples subjected to a single heat treatment, but if the author first subjected a high-speed steel to a high temperature treatment at about 2400° F., followed by a treatment at about 1350° F., and then, after allowing the sample to cool down, reheated to approximately 1830° F. and cooled in a strong air-blast or oil, he would find that the coercive force would be very nearly as high as that given by a single high heat treatment, but that the saturation value and the remanence would be very much higher, thus showing

again that the presence of austenite was not necessary for the development of a high coercive force.

On theoretical grounds, the presence of a non-magnetic constituent such as austenite would not make magnetising, or demagnetising, more difficult. It might make both less difficult. It had been shown by Watson¹ that when a non-magnetic micro-constituent was present in the form of a network surrounding a magnetic micro-constituent, the coercive force (or the force necessary to demagnetise the sample) was reduced on account of a shortening of the total magnetic length which it was necessary to demagnetise. When, on the other hand, the same volume of a non-magnetic constituent was present in the form of globules, the remanence and the coercive force were higher than when it was present as a network. In the original paper, those statements were fully qualified by the numerous photomicrographs and B-H curves.

Mr. J. H. WHITELEY (Stockton) wrote that Dr. Mathews had brought forward some new and interesting facts relating to the physical properties of quenched steels. The experimental work described in the paper appeared to be very satisfactory, but he wished to observe that the structure shown in the beautiful photomicrograph on Plate XXVII. was not that of a fully quenched steel. If a small section of a plain steel containing from about 0.9 to 1.5 per cent. of carbon were rapidly quenched in cold water and then tempered a short time at 200° to 250° C., the same structure could be produced. He had described it as lattice-troostite in a recent paper on the subject² and had given evidence to show that the white constituent was really austenite as Dr. Mathews apparently contended. Prior to tempering, those white areas were not to be seen; in fact, the etched specimen then had an entirely different appearance, which he (Mr. Whiteley) had termed Type III. martensite. If the speed of quenching were slackened sufficiently the lattice structure could be obtained directly, evidently because the Type III. martensite first formed had time to change during the slower cooling. Those and other considerations mentioned in the paper led him to believe that the white areas in that lattice structure were really austenite re-formed from the Type III. martensite, while the remainder passed into troostite. The facts given by Dr. Mathews appeared to support that explanation. For example, the greater magnetic hardness of the oil-quenched steels in Table II. and also their higher density might be accounted for in that way. Indeed it was difficult to see how otherwise an oil-quenched sample could contain more austenite than the same steel more rapidly quenched in water.

¹ "Permanent Magnets and the Relation of their Properties to the Constitution of Magnet Steels," *Journal of the Institution of Electrical Engineers*, June 1923, vol. lxi.

² *Journal of the Iron and Steel Institute*, 1925, No. I. p. 334.

Dr. MATHEWS replied that Mr. Kayser seemed to have overlooked the fact that the paper dealt with a discussion of "retained austenite" rather than permanent magnetism. In the course of his experiments the author employed magnetic testing along with several other methods to substantiate three new concepts, and among the materials used were several compositions that might be used for permanent magnets. The paper stated that the concepts or conclusions applied very broadly to a wide range of alloy compositions not used for permanent magnets (see Table II.), and they were of greater importance to the consideration of the hardening phenomenon than to the restricted subject of magnet steels.

Helmholz once said: "The disgrace of the nineteenth century is our ignorance concerning magnetism." Some progress had been made in the twentieth century, but there was a strong feeling that progress would be more rapid if metallurgists knew more of physics, and theoretical physicists knew more of metallurgy. There was much to learn about magnetism itself, but, fortunately, a great deal was known about the making and use of magnet steels.

His own ideas of coercive force and retentivity were in accord with Dr. Hopkinson's definitions, and in accordance with those definitions he still felt that in a permeameter test the "residual magnetism" was "coerced" with a "demagnetising force." It was a great surprise to learn that neither "remanence" nor "coercive force" gave any indication of permanence. It must have been a great mistake when he had installed a permeameter nearly twenty-five years ago so that he might know something of the magnetic characteristics of the various products he was manufacturing for magnetic purposes. The residual magnetism and coercive force were the criteria which had been relied upon during all that period in determining the usefulness of many thousands of tons of magnet steels of many types and for predicting their suitability for various applications where a satisfactory amount of flux, together with sufficient stability or permanence, was desired.

Mr. Kayser did not accept the third conclusion reached by the author, but gave no facts that controverted it. It was not stated in the paper that the presence of austenite was the reason for the extremely high coercive values of some cobalt steels. It was merely pointed out that when two steels were hardened in such a way that one retained more austenite than the other, the one with most austenite would show the higher coercive force, and, conversely, when that austenite was converted to martensite by a liquid air treatment there was a decrease in the coercive force. The remarks upon high-speed steel were not to the point, for Scott showed, years ago, that the austenite of high-speed steel behaved just like other austenite in chromium, tungsten, or cobalt steels. The fact that a method of heat treatment other than that described by the author gave different magnetic results did not disprove the third conclusion; in fact, it had nothing to do with it.

The author made no attempt to explain on theoretical or other

grounds why retained austenite raised the coercive force. It might be observed, however, that since austenite was non-magnetic an excess of that constituent would lower all the magnetic properties, and that possibly there was a critical amount which gave the maximum coercive force, and possibly also there was a critical dispersion necessary, for it seemed unlikely that the visible particles seen under high-power magnification were the real cause of greater coercive force. There might be some γ -iron atomically dispersed.

The author did not understand upon what ground Mr. Whiteley assumed that Plate XXVII. did not represent a fully quenched steel. Plate XXVI. showed that steel as hardened from 2000° F.; the sample was not tempered by any form of reheating, but was given a treatment in liquid air only. Mr. Whiteley seemed to agree that the white areas were austenite. It would seem as though a light section of an alloy steel of 1.0 per cent. carbon, quenched from a temperature as high as 2000° F., ought to be fully hardened.

The reason for presenting the paper was to stimulate further research along lines which the paper naturally suggested. It was felt that a new viewpoint in regard to what actually happened in hardening had been presented, but much remained to be done to extend our knowledge of the quantitative relationship of α - and γ -irons in hardened steels.

Iron and Steel Institute.

DENDRITIC SEGREGATION IN IRON-CARBON ALLOYS.

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It is well known that iron-carbon alloys crystallise, like most solid solutions, through the formation of dendritic crystals, and that these dendrites are heterogeneous because of the gradual segregation of carbon and of other impurities in the portions late in solidifying. In accordance with the mechanism of the formation of a solid solution, the main axes, which crystallise first, should be freest from carbon and impurities, while the fillings or interstices last in solidifying should contain the greatest amount of these elements. This is known as dendritic segregation. While the phenomenon of diffusion tends to promote chemical homogeneity, the latter is rarely complete and the dendrites generally remain chemically heterogeneous. This may be referred to as persistent dendritic segregation.

Stead contended long ago that this persistent dendritic heterogeneity was due to phosphorus, because of its resistance to diffusion. Upon treatment with a suitable copper reagent, copper is deposited in the axes of the dendrites because they are quite free from phosphorus, while the fillings, being rich in that element, remained free, or relatively free, from copper deposition. Stead contended further that the phosphorus which had segregated in the fillings caused the rejection of the carbon from the fillings into the axes, thereby increasing chemical dendritic heterogeneity. The dendritic axes, therefore, according to Stead, should contain much carbon and little phosphorus, while the fillings should be rich in phosphorus and quite free from carbon. Stead's views, which were well supported by experimental evidence, have been generally accepted. Professor

Le Chatelier, however, has challenged their correctness, and argued that oxygen rather than phosphorus was the cause of persistent dendritic segregation. The experiments about to be reported were undertaken with a view to throwing some light on this question.

ELECTROLYTIC IRON MELTED IN VACUUM.

About 100 grammes of the purest electrolytic iron obtainable were melted in an alumina crucible placed in an Arsem vacuum furnace. Etching a suitable polished section of the resulting small ingot with the Le Chatelier cupric reagent¹ failed to bring out any dendritic structure. This was to be expected, since the revelation of dendrites by an etching method necessarily depends on the existence of dendritic segregation, which makes possible a selective action of the reagent, and segregation cannot occur in the complete absence of segregating elements. The microstructure of this vacuum-melted electrolytic iron is shown in Fig. 1 (Plate XXX.). As deposited, this iron contained 0.013 per cent. carbon. After remelting, it contained 0.06 per cent. carbon, the difference having been absorbed from the heating element of the furnace. As no pearlite whatever could be detected under the microscope, it may be inferred that α -iron is capable of retaining as much as 0.06 per cent. carbon in solid solution.

ELECTROLYTIC IRON MELTED IN AIR.

The same weight of electrolytic iron was melted under exactly the same conditions, but this time with free access of air. Treatment with the Le Chatelier reagent again failed to reveal any dendritic structure. It seems justifiable, therefore, to infer that oxygen alone cannot cause persistent dendritic segregation.

The microstructure of this air-melted electrolytic iron is shown in Fig. 2. Although the iron contained, after remelting, 0.05 per cent. carbon, no pearlite could be discovered under the microscope.

¹ The reagent used contained 2 grammes of CuCl_2 , 3 grammes of MgCl_2 , 4 cubic centimetres of HCl , 36 cubic centimetres of water, and 200 cubic centimetres of methyl alcohol.

ELECTROLYTIC IRON AND CARBON MELTED IN VACUUM.

The same weight of electrolytic iron was melted in vacuum under exactly the same conditions, but with the addition of some sugar charcoal. The resulting ingot contained 0.35 per cent. carbon, 0.01 per cent. phosphorus, and traces only of other elements. Etching with the Le Chatelier reagent brought out the dendritic structure reproduced in Fig. 3 (Plate XXX.), an evidence of persistent dendritic segregation. Since this alloy is practically free from phosphorus and oxygen, it would seem as if the presence of one at least of these elements is not essential to the occurrence of persistent dendritic segregation.

Carbon being, in this instance, the only element dissolved in iron at the time of solidification, the conclusion is warranted that α -ferrite is capable of retaining some carbon (or carbide) in solution, and that the ferrite present in the fillings contains more dissolved carbon than the ferrite in the axes, copper having been, as usual, selectively deposited on the purer ferrite of the axes, as clearly seen in Fig. 3 under oblique illumination. Carbon, therefore, can produce persistent dendritic segregation in the practically complete absence of any other element, oxygen included. It is well known, however, that carbon diffuses readily, and the authors have found that when solidification and subsequent cooling of pure iron-carbon alloys take place very slowly, a dendritic structure can no longer be produced owing to the obliteration by diffusion of carbon segregation.

The microstructure of this sample is reproduced in Fig. 4. It is clearly of the Widmanstätten type, the free ferrite being located chiefly in the cleavage planes of the original austenitic grains. This, according to Belaiew, must be due (a) to rapid cooling through the critical range, time being denied for the ferrite to reach the boundaries of the grains and thus to produce a network type of structure, or (b) to very slow cooling through the range, resulting in undercooling and in a subsequent rapid precipitation of free ferrite. It is not believed that in the experiments here described the cooling could have been sufficiently slow to induce undercooling. The formation of these two types of microstructures will be discussed by the authors in a subsequent paper.

ELECTROLYTIC IRON AND CARBON MELTED IN AIR.

On melting electrolytic iron and carbon under the same conditions with free access of air, an alloy was produced containing 0.36 per cent. of carbon and 0.01 per cent. of phosphorus. Etching with the cupric reagent revealed the dendritic structure exhibited in Fig. 5 (Plate XXXI.). It resembles the structure of the preceding sample, there being no indications that the presence of oxygen in this sample has increased dendritic segregation. The microstructure also resembles the microstructure of the vacuum melted sample.

ELECTROLYTIC IRON AND PHOSPHORUS MELTED IN VACUUM.

Melting electrolytic iron and phosphorus in vacuum resulted in an alloy containing 0.09 per cent. of phosphorus. Treatment with the Le Chatelier reagent brought out a dendritic structure (Fig. 6), copper having been deposited on the ferrite of the axes because they contain less phosphorus than the ferrite in the fillings. Here again the reagent has acted selectively by depositing copper on the purer ferrite. We infer from this that phosphorus, without the assistance of any other element, oxygen included, can produce persistent dendritic segregation, and that 0.09 per cent. is sufficient. We have no explanation to offer for the occurrence in this sample of many rounded particles consisting of white rings and dark cores. The microstructure is shown in Fig. 7. Although the metal contained 0.06 per cent. carbon, no pearlitic areas could be detected.

ELECTROLYTIC IRON, CARBON, AND PHOSPHORUS MELTED
IN VACUUM.

An alloy was obtained containing 0.50 per cent. carbon and 0.10 per cent. phosphorus. The intense dendritic segregation resulting from the presence of both carbon and phosphorus is shown in Fig. 8, and the microstructure of this ingot in Fig. 9 (Plate XXXII.).

ELECTROLYTIC IRON, CARBON, AND PHOSPHORUS MELTED IN AIR.

The dendritic structure of this alloy is shown in Fig. 10, and its microstructure in Fig. 11. Here again the presence of oxygen does not seem to have increased the dendritic segregation caused by carbon and phosphorus.

HIGH PHOSPHORUS-CARBON ALLOY.

An alloy was prepared containing 0.17 per cent. carbon and 0.39 per cent. phosphorus for the purpose of investigating the action of a large percentage of phosphorus on dendritic segregation. The macrostructure of this alloy after etching with the Le Chatelier reagent is illustrated in Fig. 12, which reveals an intense dendritic segregation. Upon examination under higher magnification it was found that the axes of the dendritic pattern consisted of pearlite, while the fillings contained ferrite only. The action of phosphorus in expelling carbon, described by Stead, had been here so intense that the carbon, and hence the pearlite, had been completely driven from the fillings rich in phosphorus into the axes poor in that element. Seeing that the macro-dendritic structure now consists of pearlitic axes and of ferrite fillings, it can be brought out by etching with nitric acid (Fig. 13, Plate XXXIII.), as phosphorus segregation has no longer to be depended upon for its revelation. The pearlitic character of the axes is shown under high magnification in Fig. 14.

CONCLUSION.

The following conclusions appear warranted :

1. The presence of oxygen alone in pure iron is not sufficient to produce persistent dendritic segregation.
2. Phosphorus in the substantial absence of any other element may cause persistent dendritic segregation.
3. Carbon in the substantial absence of any other element may cause persistent dendritic segregation, provided solidification has been sufficiently rapid to prevent its complete diffusion, from which it follows that α -ferrite is capable of retaining some carbon

in solution, and that the ferrite in the fillings contains more carbon than the ferrite in the axes.

4. The presence of both carbon and phosphorus results in a more intense and persistent dendritic segregation.

5. The presence of 0.39 per cent. phosphorus in an alloy containing 0.17 per cent. carbon causes the carbon to be completely driven from the fillings into the axes, resulting in dendrites consisting of pearlitic axes and of ferrite fillings.

6. The presence of oxygen in alloys containing phosphorus or carbon, or both, does not appear to intensify dendritic segregation.

7. α -ferrite is capable, after slow cooling, of retaining in solution at least 0.06 per cent. of carbon.

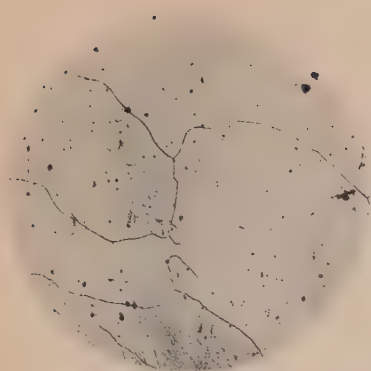


FIG. 1.—Electrolytic Iron melted in vacuo. C=0.06 per cent., P=0.011 per cent., S=0.034 per cent. $\times 80$.



FIG. 2.—Electrolytic Iron melted in air. C=0.05 per cent., P=0.015 per cent., S=0.020 per cent. $\times 100$.

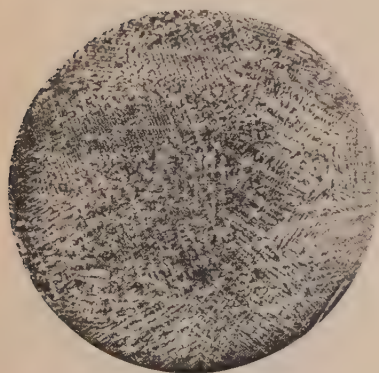


FIG. 3.—Electrolytic Iron and Carbon melted in vacuo. C=0.35 per cent., P=0.01 per cent. Etched with Le Chatelier solution. Oblique illumination. $\times 4$.

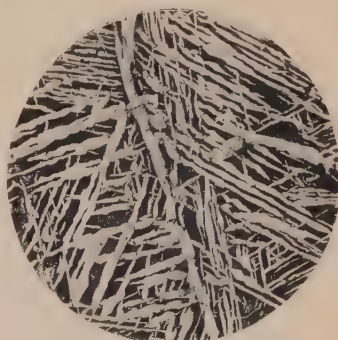


FIG. 4.—Electrolytic Iron and Carbon melted in vacuo. C=0.35 per cent., P=0.01 per cent. $\times 80$.

NOTE.—Figs. 1, 2, 3, 6, 8, 10, 12, have been reduced to two-thirds linear.
Figs. 4, 5, 7, 9, 11 have been reduced to one-half linear.

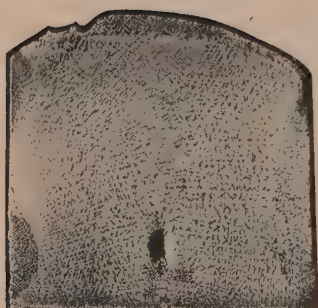


FIG. 5.—Electrolytic Iron and Carbon melted in air. C=0.36 per cent., P=0.01 per cent. Etched with Le Chatelier reagent. Oblique illumination. $\times 4$.

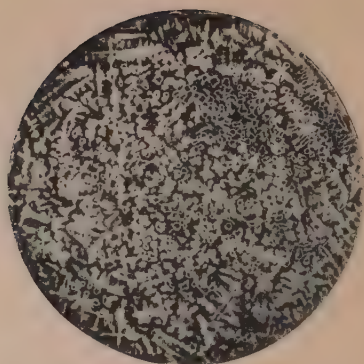


FIG. 6.—Electrolytic Iron and Phosphorus melted in vacuo. P=0.09 per cent., C=0.06 per cent. Etched with Le Chatelier reagent. Oblique illumination. $\times 4$.

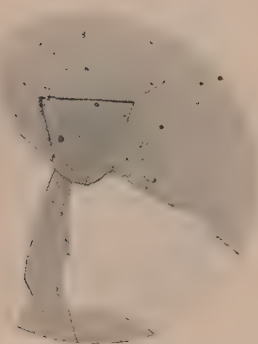


FIG. 7.—Electrolytic Iron and Phosphorus melted in vacuo. C=0.06 per cent., P=0.09 per cent. $\times 80$



FIG. 8.—Electrolytic Iron, Carbon and Phosphorus melted in vacuo. C=0.50 per cent., P=0.10 per cent. Etched with Le Chatelier reagent. Oblique illumination. $\times 4$.



FIG. 9.—Electrolytic Iron, Carbon and Phosphorus melted in vacuo. C=0.50 per cent., P=0.10 per cent. $\times 80$.

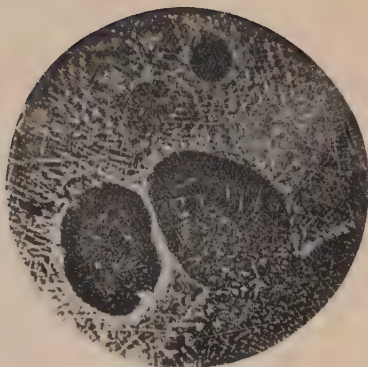


FIG. 10.—Electrolytic Iron, Carbon and Phosphorus melted in air. Carbon=0.50 per cent., Phosphorus=0.10 per cent. Etched with Le Chatelier reagent. Oblique illumination. $\times 4$.

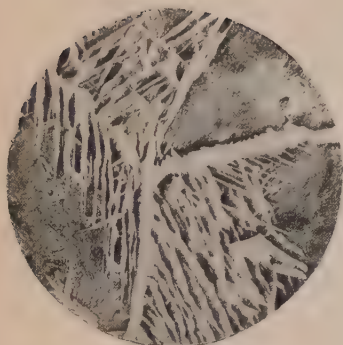


FIG. 11.—Electrolytic Iron, Carbon and Phosphorus melted in air. Carbon=0.50 per cent., Phosphorus=0.10 per cent. $\times 80$.



FIG. 12.—Carbon=0.17 per cent., Phosphorus=0.39 per cent. Etched with Le Chatelier reagent. Oblique illumination. $\times 4$.

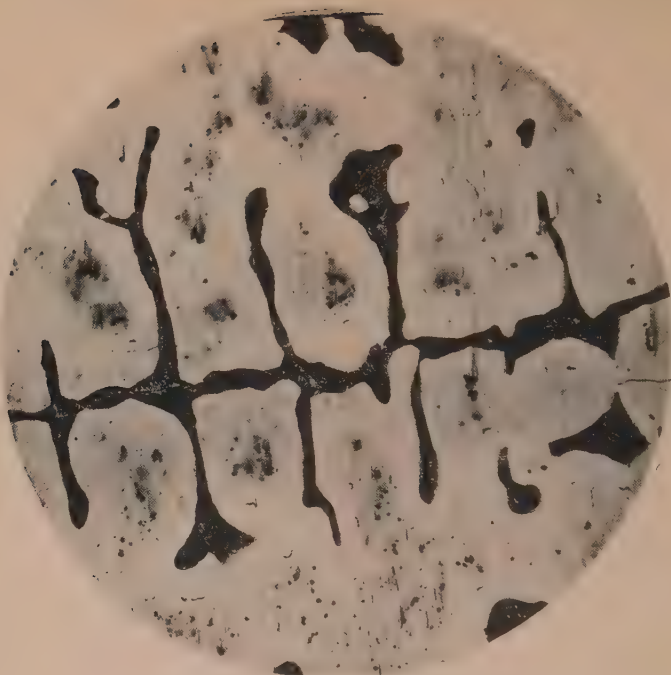


FIG. 13.—Carbon=0·17 per cent., Phosphorus=0·39 per cent.
Etched with nitric acid. $\times 60$.

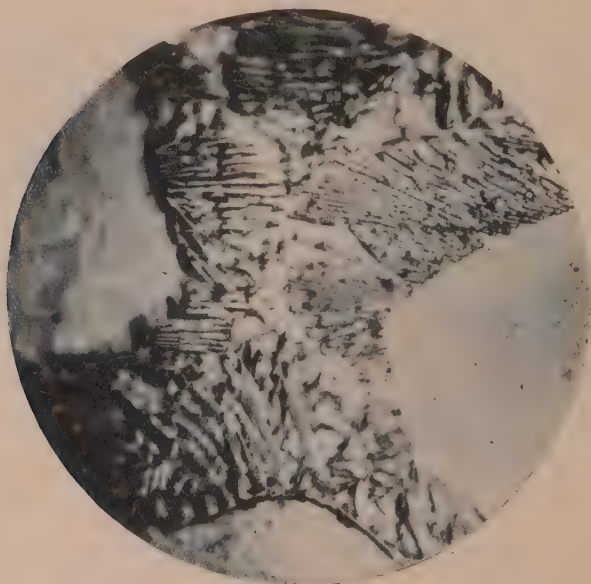


FIG. 14.—Carbon=0·17 per cent., Phosphorus=0·39 per cent.
 $\times 1000$.

[To face p.

CORRESPONDENCE.

Colonel BELAIEW (London) wrote to express his great interest and appreciation of the results arrived at by Professor Sauveur and Dr. Krivobok. He found himself in substantial agreement with the authors' views on dendritic segregation, and more especially with the views laid down in the conclusions 1, 2, 4, 5, and 6. He also quite agreed with the authors as to the possibility of ferrite retaining a certain amount of carbon (in solution or in suspension), as mentioned in clauses 3 and 7; he would be prepared to go even a little further and take up the former views of Benedicks on ferronite, with such modifications as were rendered necessary by the latest X-ray evidence on the crystal lattice.

In paragraph 3 of their conclusions the authors dealt also with the influence of carbon on segregation, with special reference to the influence of diffusion. There were a few observations which he (Colonel Belaiew) would like to offer on that particular aspect of the question.

He had studied dendritic segregation and its relation to the conditions of cooling on a series of alloys, slowly cooled down within the furnace at the Putilov works in Petrograd in 1907. Those researches were undertaken with the assistance of the head of the heat treatment department of the works, Mr. N. I. Belaiew. One of the assumptions made then by himself (Colonel Belaiew), under the influence of the ideas of Roozeboom, was that a considerable if not a complete diffusion would necessarily take place in the very slowly cooled specimen and, consequently, the greatest possible homogeneity arrived at. Those views were not shared by the writer's collaborator and friend, Mr. N. I. Belaiew, and many a friendly discussion took place in the foundry during the long hours the alloys had to cool down. In spite even of the evidence offered by the structure of the alloys, he (Colonel Belaiew) was still rather reluctant to discard at once the "homogeneity" idea, and Mr. N. I. Belaiew undertook an extensive series of investigations on a large shop-practice scale to substantiate his ideas of the persistence of segregation in steel specimens under all the usual heat treatments, like tempering, annealing, forging, and quenching. Those researches were published in 1910 in the *Journal of the Russian Metallurgical Society*, and later in the *Revue de Métallurgie* in 1912. The evidence brought forward was so striking, that the present writer finally adopted those views in their entirety. The evidence accumulated since seemed to corroborate those views, and he could not help wondering whether, when one or other of the usual methods failed to bring out segregation, the "*Révéléateur Macroscopique*" of the Putilov works should not be tried.

He also quite concurred with the authors in their view, that the axes of the steel crystals were usually pearlitic, whilst the fillings consisted of the proeutectoid element, cementite or ferrite. For instance, he might quote his alloy No. 1 with 1·80 per cent. of carbon, where the dendrites, their axes and branches, were pearlite and the fillings between the branches were made up of cementite. It might be also of interest to mention that the structure of the famous Tschernoff crystal was of the same character. The carbon content of the sample of this crystal



FIG. C.— $\times 4/3$. Tschernoff's Crystal. Oblique illumination—
Pearlite (white) and Ferrite (black).

analysed by the present writer was 0·60 per cent., and consequently the sample contained 72 per cent. of pearlite. From the accompanying photograph, Fig. C (pearlite areas white, and ferritic black) it would be seen that the axes of the crystal were pearlite and the interstices ferrite, thus supporting the views of Stead and of the authors.

However, with reference to Figs. 12 and 13 of the alloy with 0·17 per cent. carbon, whilst agreeing that the pearlitic enclosures looked like "crystallites," he would like to suggest that in actual fact the position seemed to be reversed, the dendrites being of ferrite and pearlite filling the interstices. That appeared even more clearly on Fig. 13, where the rounded-up branches were seen on the section, and might be ascribed to the high percentage of ferrite.

With reference to the authors' remarks on the microstructure reproduced in their Fig. 4, he would like to say that a structure which at a small magnification looked dendritic, might at a larger one be resolved into either the network, the Widmanstätten, or the structure of large crystals. In the absence of granulation the structure of large crystals might appear, as in Tschernoff's crystal; in other cases the two former might appear, or either of them. Therefore the actual character of the structure of the dendrites, or, as the authors style it, of the persistent dendritic segregation, could be appreciated best at lower magnification, showing the whole picture of the primary crystallisation.

Iron and Steel Institute.

THE INFLUENCE OF STRAIN AND OF HEAT ON THE HARDNESS OF IRON AND STEEL.

BY ALBERT SAUVEUR, D.Sc. (GORDON MCKAY PROFESSOR OF METALLURGY
AND METALLOGRAPHY, HARVARD UNIVERSITY, U.S.A.),

AND

D. C. LEE, D.Sc. (CHANGSHA, HUNAN, CHINA).

It has been known for many years that the strength of iron and of steel increases when these metals are heated above room temperature, becoming maximum somewhere between 250° and 425° C., and that further heating results in steadily decreasing strength. When polished samples of these metals are heated in air to the temperatures indicated, they assume a blue colour, resulting from the formation of an oxide film, hence the term "blue-heat" used to designate this range of temperature, and also the familiar statement that iron and steel are stronger at a blue-heat than at room temperature. This phenomenon is well illustrated in the curves shown in Fig. 1 as obtained in the Metallurgical Laboratory of Harvard University. It will be noted that in the case of electrolytic iron maximum tensile strength is obtained at 250° C., whilst steels containing respectively 0.10, 0.30, and 0.50 per cent. carbon reach their maximum strength at a temperature slightly in excess of 300° C. With 0.75 per cent carbon, maximum strength occurs at 400° C. It is obvious, therefore, that this "blue-heat phenomenon" does not occur at the same temperature with all grades of iron and steel, and it is probable that, as the carbon increases, the temperature imparting maximum strength likewise increases. Electrolytic iron at room temperature has a tensile strength of 40,000 lbs. per square inch, while at 250° C. its strength is 56,000 lbs. per square inch, an increase of 40 per cent. Steel containing 0.10 per cent. carbon increases in strength from 68,000 lbs. to 86,000 lbs., or 26 per cent.; steel with 0.30 per cent. carbon from 80,000 to 88,000, or 10 per cent.; steel with 0.50 per cent. carbon from 110,000 to 126,000, or 15 per cent.; and steel with 0.75 per cent. carbon from 140,000 to 146,000, or 4.3 per cent. Iron and very

soft steel increase in strength by blue-heating very much more than higher-carbon steel. It should also be noted that the increase of strength is preceded by a decrease of that property, and that at 100° C. all samples tested exhibited a strength lower than that at room temperature.

Since it is well known that the hardness of a metal generally

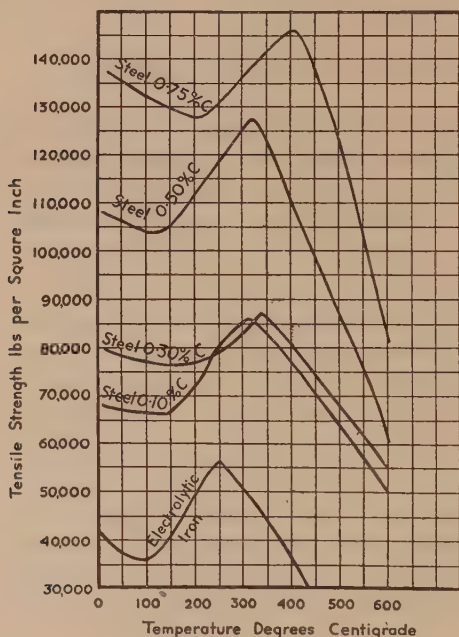


FIG. 1.—Tensile Strength of Carbon Steels at Various Temperatures.

increases with its strength, it was naturally inferred that in their respective blue-heat ranges iron and various grades of steel must be harder than at room temperature. To verify this inference experiments were conducted by applying the Brinell test for hardness while maintaining the metal at a given temperature, and the results obtained plotted as shown in Fig. 2. It will be noted that maximum hardness is obtained in the blue-heat ranges, and that these correspond quite closely with the temperatures at which maximum strength was observed. With 0.80 per cent. carbon there is but a slight increase of hardness, and with 1.25 per

cent. carbon none at all, which is also in accord with the action of blue-heating on the strength of high-carbon steel. It seems justifiable to infer that the increase of strength and of hardness in the blue-heat range results from an increase of strength and hardness of the ferrite present in the metal, being greatest, therefore, in iron and low-carbon steel, because these are made

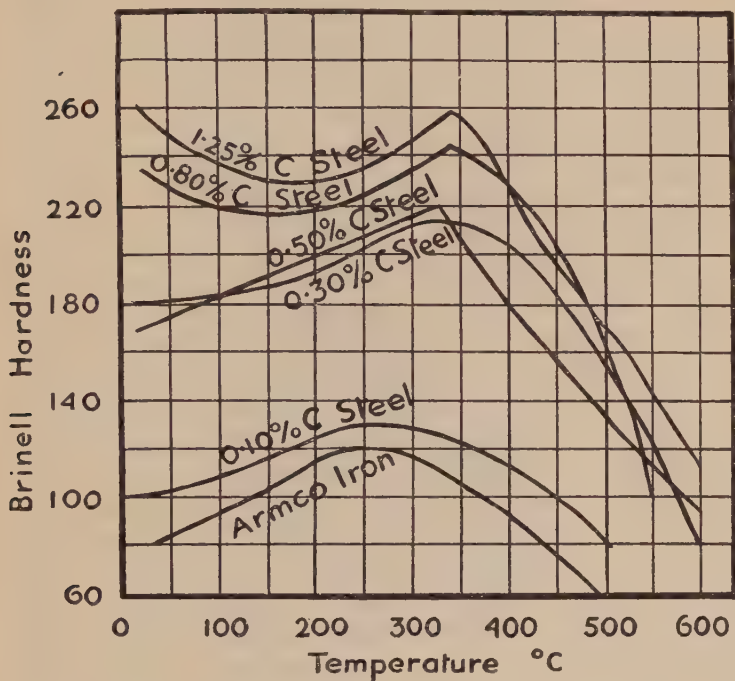


FIG. 2.—Brinell Hardness of Carbon Steels at Different Temperatures.

up almost exclusively of ferrite, and practically nil in eutectoid and hyper-eutectoid steels because of the absence of free ferrite.

When iron or steel is deformed—that is, strained beyond its elastic limit at room temperature—its tensile strength and hardness are materially increased, which is generally expressed by stating that cold-working increases the strength and hardness of these metals. It was thought advisable to find out whether this increase of strength through straining or deformation was

confined to work performed at room temperature. This could easily be done by testing the hardness near the broken ends of test-pieces that had been ruptured, and therefore deformed, at different temperatures. The results shown in Fig. 3 were

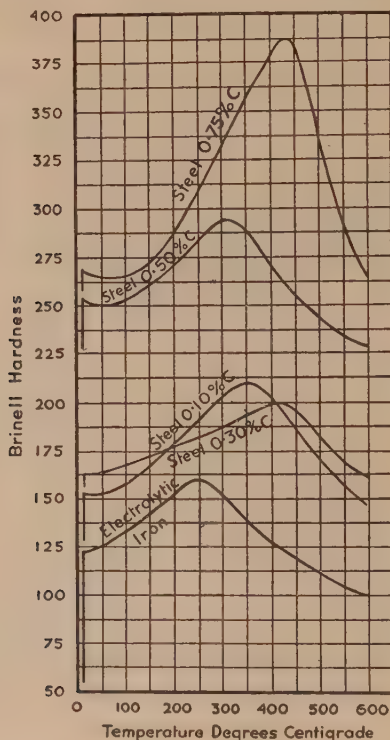


FIG. 3.—Brinell Hardness of Carbon Steels at Room Temperatures after Straining at Various Temperatures.

obtained. It will be noticed that while deformation produced at room temperature results in marked increases of hardness, deformation at higher temperature causes still greater increases of hardness, and that maximum increases are always obtained after deformation in the respective blue-heat ranges of the samples tested. Moreover, unless deformations are produced at temperatures exceeding some 580° to 680° C., the metals are harder than they were in their normalised, unstrained conditions. This

range of temperature may logically be taken as the demarcation between cold- and hot-working, the former resulting in hardening, the second in softening, iron and steel in comparison with their hardness in their normalised condition. An exception to this rule occurs in the case of electrolytic iron, which is so soft in its normalised condition that working at any temperature hardens it. Its Brinell hardness is increased from 48 to 120 by tensile stresses at room temperature sufficient to rupture it, and to 160 when the stress is applied at 250° C. Rupture at 600° C. produces a Brinell hardness of 100. Steel containing 0.10 per cent. carbon had a Brinell hardness of 130 in its normalised state, which was increased to 153 by straining at room temperature, and to 212 by straining at 350° C. Rupture at 600° C. gave a hardness of 140, and at 800° gave 120. With 0.30 per cent. carbon the hardness increased from 150 to 163 when ruptured at room temperature, and to 202 when ruptured at 385° C. After breaking at 680° C. the hardness was reduced to 137. Steel containing 0.50 per cent. carbon increased in hardness from 225 to 250 by rupture at room temperature, and to 293 after rupture at 340° C. Tensile testing at 680° C. reduced its hardness to 196. With 0.75 per cent. carbon the original hardness of 260 was increased to 269 and to 387 respectively by rupture at room temperature and at 440° C. Straining at 645° C. reduced it to 241. These tests clearly bring out the greater increase of hardness resulting from deforming iron and steel in the blue-heat range over the increase of hardness caused by deforming at room temperature. These results are contrary to the belief generally held that the lower the temperature the greater is the hardening effect of cold-work.

The effect of heating on the hardness of iron and steel after different degrees of strains produced at room temperature has also been investigated. To that end bars were subjected to the tensile test and then cut in several pieces, as shown in Fig. 4. The straining resulting from the tensile stress was maximum at 1, less at 2 and 3, and still less at 4 and 5. In this way, samples were obtained that had undergone different amounts of deformation at room temperature. The six samples, A, B, C, D, E, and F, were then heated to various temperatures and their hardness ascertained before and after heating, proceeding as follows :

the surface of sample D in contact with C was tested for hardness, thus obtaining the hardness of the most severely strained portions of the bar ; sample C was then heated to the desired temperature and the hardness of the surface of C facing D ascertained. The difference between the two readings indicated the increase or decrease of hardness resulting from the heating. The same method was applied to all samples.

It will suffice to report the results obtained in testing in this

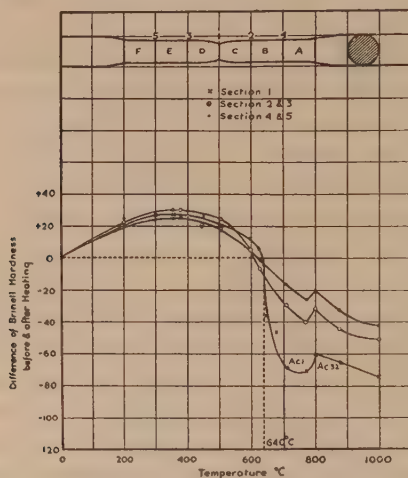


FIG. 4.—0.50 per Cent. Carbon Steel.

fashion bars of steel containing 0.50 per cent. carbon. They have been plotted in Fig. 4. The co-ordinates are temperatures to which the samples were heated and increase or decrease of Brinell hardness. The results obtained by testing the portions of the bars numbered 1, 2, 3, 4, and 5, corresponding with three different degrees of straining, are shown. The following conclusions may be drawn: Heating cold-worked steel above atmospheric temperature results in an *increase* of hardness which is maximum at about 350° C., that is, in the blue-heat range of the steel tested. Heating to 600° C. has no effect on the hardness, while heating at higher temperatures softens the metal. For temperatures lower than 600° C. there is no difference in the behaviour of the samples, but at higher temperatures the most

severely strained samples, and hence the hardest, lose their hardness more rapidly than the other two series. Similar results were obtained with steel containing different percentages of carbon, and also with electrolytic iron. With 0.10 per cent. carbon, however, the hardness of the cold-worked steel begins to decrease on heating to about 500° C., and that of electrolytic iron on heating to 425° C. Instead of softening cold-worked iron or steel by heating them to some 200° to 300° C., therefore, their hardness is actually increased. Without attempting here to explain the phenomena which have been reported, the salient features of these experiments may be briefly stated:

1. On heating normalised iron and steel above atmospheric temperature their strength and hardness are at first slightly decreased, this being followed by an increase which reaches its maximum in the blue-heat range of temperature.

2. In pure iron the blue-heat phenomenon occurs in the vicinity of 250° C., with 0.10, 0.30, and 0.50 per cent. carbon at about 325° C. and with 0.75 per cent. carbon near 400° C.

3. The increase of strength and hardness observed in the blue-heat range probably results from the strengthening and hardening of the ferrite, little if any increase being detected in the absence of that constituent.

4. Straining normalised iron or steel above their elastic limit increases both strength and hardness, and the increase is more marked as the temperature at which straining occurs rises above atmospheric temperature, being maximum after straining in the blue-heat range. When the temperature exceeds some 580° to 680° C. the straining of the metal results in decreased hardness. This range of temperature may be taken as the demarcation between cold-working and hot-working.

5. The hardness resulting from cold deformation at room temperature is increased further by heating the metal above atmospheric temperature, reaching a maximum after heating in the blue-heat range, irrespective of the degree of deformation. To soften the strained metal it is necessary to heat it to a temperature exceeding 425° C. for electrolytic iron, 500° C. for steel containing 0.10 per cent. carbon, and 600° C. for steel containing 0.50 per cent. carbon.

Iron and Steel Institute.

STEEL MOULDING SANDS AND THEIR BEHAVIOUR UNDER HIGH TEMPERATURES.

By A. L. CURTIS (CHATTERIS, CAMB.)

[This paper was presented for discussion at the Autumn Meeting after publication in the *Carnegie Scholarship Memoirs* (vol. xiv., 1925). The research work was carried out with the aid of grants from the Carnegie Research Fund of the Institute.]

DISCUSSION.

Sir ROBERT HADFIELD, Bart. (Past-President), thought that the members owed the author a deep debt of gratitude for the immense amount of work he had put into its preparation. A few years ago rule-of-thumb methods were much applied to the mixing of sands and the preparation of compositions into which steel was poured; but owing to the efforts of men like the author and Mr. Searle, of Sheffield, foundry materials were now being studied on a scientific basis, and much better castings were obtained, showing that the steel which was formerly blamed for being bad was, after all, not at fault. Unsound castings were still made, but they were gradually disappearing, thanks to the scientific study of the exact mixtures and compositions now being made. An enormous number of tests were set out in the paper. Not only was the composition given, but the permeability, the tensile strength, and the compression strength of the sand and a number of other qualities, all of which it was necessary to examine before it was known which was the correct material to use in a steel foundry. He hoped the author would continue his labours and add more much-needed information in order that better steel castings might be made.

Professor THOMAS TURNER (Member of Council) considered that the question of the composition and character of the sand of which moulds were made was of the utmost importance. The author had referred to the extensive work of the American Foundrymen's Association and to the standard tests which they had produced. Work had been done in Great Britain by the British Cast Iron Research Association, and some work had just been published by one of his students, Mr. Moss, dealing with an examination of sands in the Birmingham district, not so much for steel melting, but more particularly for use in cast iron melting and for brass foundry purposes. He was interested to note that the author had obtained such good results with

the oxy-hydrogen blowpipe method of determining the refractoriness, or temperature of softening of the samples. At Birmingham they had generally used the recognised Cramer and Seger form of Deville furnace, using the Seger cone. It was not ideal perhaps, but it had answered their purpose very well. They had also adopted a permeability apparatus not very different from that the author described and on the same principle. Obviously many properties had to be considered in a sand if it were to be suitable for foundry purposes. On the one hand, it must not be too fine, too argillaceous in character, or it would be deficient in permeability; it must not be too dry or it would be deficient in tenacity; it must not be too readily melted or it would scab the metal and produce other difficulties. The question of porosity was of great importance. That brought him to the question of size, or the grading of the sand, a matter which had been dealt with very fully in the paper. He thought the paper was the most comprehensive contribution to the subject the Institute had yet received; the author was well known as a most eminent authority on that branch of the subject, so that the members were indebted to him for a paper which would be a standard of reference in connection with the sands he had examined.

Mr. H. B. TOY (Saltburn-by-the Sea) said that all interested in the manufacture of steel castings would admit that the first and most important detail was to have the quality of the steel suitable for the purpose, and the next matter of importance was to have a suitable sand. In some foundries that he visited abroad he was much impressed by the skilful way in which the sands were mixed to suit castings of varying designs and weights. It was very necessary to have a sand which was highly refractory mixed with a suitable binder and to ventilate the moulds properly.

Mr. D. SILLARS (South Bank, Yorks) asked the author whether by the oxy-hydrogen blowpipe process he was able to take an unknown sand and identify the fault, if it existed, arising from the presence of a particular mineral, without resort to the microscope?

CORRESPONDENCE.

Mr. J. FERDINAND KAYSER (Sheffield) wrote that, after a most careful reading of the section, "Method Adopted and Apparatus Used for Testing Steel Moulding Sands under High Temperatures," he completely failed to understand how the author had obtained his temperature measurements. Seger cones had not a definite melting point and were quite useless for calibration purposes. Also, under the conditions of the experiments, black-body conditions would not, by

any means, be obtained. Many of the temperatures at which photographs were obtained were well within the range of a thermocouple pyrometer, and it would have very much increased the value of the work if that means of temperature measurement had been used. He (Mr. Kayser) had frequently used the Davon super-microscope for the observation of surfaces at high temperatures, and had never yet found the need for any specially designed lenses, although he had worked with the primary objective not more than 3 inches from the heated sample. In his work, he always protected the optical system by means of a small water-tank containing a suitable aniline dye to act as a combined heat absorber and colour screen.

Many of the photographs showed so little detail and were of such a nature that, unless the author could supply an interpretation of the structure, or rather the lack of structure, shown, it was impossible to understand them. Those remarks applied to practically all the photographs of Groups XIII., XIV., XV., XVI., and XVII.

Turning to the practical side of the question, he (Mr. Kayser) suggested that there was no relationship whatever between the behaviour of a moulding sand when exposed to a naked flame and a sample of a similar sand used as a mould facing. One of the characteristics of the high carbon chromium steels and of manganese steels was that they could be cast into sand moulds at a very high temperature and, when cold, would come out of the sand remarkably clean. Other metals, with a very much lower melting point and cast at a lower temperature into moulds made from the same batch of sand, would produce castings which required hours of chipping and shot blasting before they were at all presentable.

He (Mr. Kayser) had endeavoured to explain the above facts and, although he had been unable to obtain any conclusive results, he was inclined to think that steels which came out of the moulds very clean actually fluxed the sand facing immediately before freezing, and that the difference between the coefficients of contraction of the resulting glass and the solidified metal caused the complete spalling away of the former, leaving a remarkably good finish on the surface of the casting. On those grounds, he was inclined to think that sands which the author would classify as inferior would, on occasion, produce the cleanest castings.

Mr. FREDERICK A. MELMOTH (Braintree) wrote that the paper would, without doubt, serve as an admirable book of reference in considering the value of any particular sand for steel moulding. Whilst accepting the author's opinion as to the value of chemical analysis, it was very easy to over-estimate such value. It was quite intelligible that in the manufacture of heavy castings, where the sand was subjected to high temperatures and pressures for a considerable time, the effect of various impurities of a fluxing nature would be very pronounced. That effect was shown as a general rule on those portions of the mould over which

large quantities of steel were compelled to pass during the pouring of the casting. In the case of light or medium sized castings of the type discussed by the author, the importance of a high degree of refractoriness, or, in other words, a low content of fluxing elements, was not only not so great, but contrariwise too high a refractoriness might even be the source of considerable trouble.

Whilst not depreciating the usefulness of chemical analysis in connection with moulding sands, he considered that any dogmatic attitude based purely on chemical analysis would result in erratic conclusions as to the value of the sand for light steel castings.

The author's conclusions regarding variations which occurred from time to time in argillaceous sands used to give the necessary bond to facing sand mixtures would no doubt be accepted by all foundrymen engaged in the production of greensand castings. The point raised was one of very great value, and there was no doubt that sometimes extremely unsatisfactory results were obtained which could be attributed to no other cause than variation in the supply of that material. That was so much the case in his own experience that he had found it necessary to carry out daily tests in order to maintain a reasonable degree of consistency in his facing sands.

Analysis being obviously of very small value in that instance, as the material varied enormously even throughout one truck load, he found that the simple test of shaking up a weighed quantity with a given bulk of water, and allowing the mixture to settle, afterwards measuring the layers of deposited sand and clayey material, gave a basis on which the amount of silver sand required to produce regular results could be quickly calculated on the spot. Such tests were so simple, and could be so quickly carried out, that they could be used as a means of control during the actual production of the facing sands, and delays due to lengthy analytical processes did not enter into the question.

With reference to the chapter on artificial steel facing sands in which examples of American synthetic sands were given, he (Mr. Melmoth) had carried out personally a good deal of work in connection with similar mixtures. Many different fireclays were used, and there was no doubt that a perfectly satisfactory facing sand for small castings could be made in that manner. Its use, however, was suspended owing to one inherent drawback. Using fireclay as a bond for greensand castings the moulds had to be closed almost immediately after they were made, otherwise the mould face dried off to such an extent as to become absolutely friable. While castings produced under perfect conditions were in every way satisfactory, others produced under normal conditions, where moulds were necessarily allowed to lie for varying periods of time before closing, were very poor indeed, the surface of the mould washing away in a quite hopeless manner.

The author's remark regarding the improvement effected by the use of a certain amount of previously used sand was in accordance with his own experience. Assuming such used sand to be free from

slag or a surplus of fine dust, it was certainly quite as good as the original silver sand, and if used in reasonable proportions, possibly better. The main point to be remembered was that in heap sands the percentage of fine dusty matter was continually increasing, and that some must be removed from that portion which was used for making up facing sand mixtures. Otherwise the effect of such additions was the gradual reduction of the permeability of the facing sand mixture.

In his own experience the very fact of the variability of naturally bonded sands had rendered such careful analytical and physical testing as was described by the author more or less abortive. The knowledge that such variations were a perpetual occurrence led him to accept no tabulated figures of either analytical content or physical properties which were obtained on small samples as being truly representative of the behaviour of the sand in actual workshop conditions.

Mr. A. B. SEARLE (Sheffield) wrote that everyone who had had to investigate the properties of different batches of St. Erth sand would agree with the author's conclusion as to the great variations which sometimes occurred. Whether knowledge was as yet sufficiently advanced to enable artificial facing mixtures, of adequate constancy and of low price, to be prepared from the variable materials available, was more doubtful, though there could be no question that many of the mixtures now in use were a great improvement on the raw sands formerly employed.

The chief difficulty to be overcome was to separate the sand grains into sufficiently uniform grades or sizes, and afterwards to make a sufficiently intimate mixture of the various materials, particularly when there were so many different sizes of grains to be considered. So many important factors came into play that until much more research work had been done on the subject, the complete solution of the problem seemed out of sight.

The necessity for making adequate tests of composition, grain-size, permeability, strength, and refractoriness should be more fully realised than was often the case, and the author had done good service in calling attention to that. In two important particulars, however, caution appeared necessary :

1. His own experience with the use of the oxygen blowpipe in the manner suggested had convinced him that the author's method, at any rate in his (Mr. Searle's) hands, was less reliable than when the test-pieces were heated uniformly in a small testing-furnace and not merely superficially as the author suggested. Indeed, he had repeatedly found that conclusions drawn from superficially heated materials were seriously misleading. So that, in spite of the difficulty often experienced in heating small pieces in a testing furnace, he regarded the results of that method as more reliable. The friability and distortion mentioned by the author could be avoided with adequate care.

2. The chemical analysis of a sand bore so little relation to its refractoriness that any conclusion from the former with respect to the latter was unwise except in the most extreme cases. In particular, comparisons based on the alumina and alkali contents of a sand were liable to serious error.

He could not agree with the author's opinion that "the value of ultimate chemical analysis cannot be over-estimated for checking the stability" of sands and mixtures. There were certain wide limits within which a chemical analysis was very valuable for such a purpose, but for close comparisons it was almost useless. That that must necessarily be the case was clear when it was remembered that sands and mixtures were complex mixtures of several (sometimes many) minerals, and that ultimate chemical analysis gave little or no clue to the nature of those minerals. The author's conclusions, based on the alumina and alkali in some sands and clays, were of small value unless care were taken to distinguish the alumina present as clay from that present as felspar or mica, and similarly with the alkalies. If the author had said that an accurate mineralogical analysis was invaluable, he would have made a much more correct statement, but, unfortunately, such an analysis was even more difficult than a chemical one.

It was difficult to understand why the author should expect any close relation between the permeability and strength of a rammed mass of sand, unless the sizes and shapes of the grains were also taken into account. Nor was there any sound reason for supposing any relation to exist between *average* grain-size and permeability. It had been previously shown that if all the grains were the same size, the permeability was constant, and that with particles of several sizes no close comparisons could be made, because there could be no certainty as to the precise distribution of the grains.

However much one might differ from the author's conclusions, the large amount of experimental data in his paper would be of great value to others working in the same field.

Mr. A. L. CURTIS, in reply, stated that the rule-of-thumb methods for the mixing of sands referred to by Sir Robert Hadfield as being in vogue a few years ago were, he believed, still in use in not a few steel foundries to-day, with more or less unsatisfactory results. That seemed apparent from the wide differences in the permeability and crushing strength figures obtained as the result of a number of tests on steel facing sand mixtures in current use. He quite agreed that steel was often blamed for faults which lay in the sand, although, as pointed out by Mr. Toy, the quality of the steel was of primary importance. It was very satisfactory to learn that Sir Robert thought unsound steel castings were gradually disappearing as a result of scientific study. The large number of tests carried out were made with that end in view.

He (Mr. Curtis) was interested to learn that one of Professor Turner's students was making a study of the Birmingham red moulding sands for casting brass and iron, but, as no doubt Professor Turner realised,

the temperatures at which those metals were cast was considerably below that of molten steel, consequently the same difficulties would not be encountered.

He noted with particular interest that at Birmingham University Seger cones were used in the Cramer-Seger type of Deville furnace for determining refractoriness. No doubt there were authorities who disagreed as to the value of Seger cones as temperature indicators, but they were a universally accepted medium for estimating high temperatures in commercial practice. Perhaps they were not ideal, but in practice they had been found to answer the purpose very well.

It was also interesting to learn that the permeability apparatus adopted by Birmingham University was on the same principle as that described in the paper.

With the exception of porosity, the qualities mentioned by Professor Turner as being essential for a good moulding sand were in accordance with his own views, but the great difficulty in making accurate determinations of pore space in argillaceous sands detracted, in his opinion, from the value of the test.

The point raised by Mr. Toy as to the importance of using a suitable sand, and altering its condition to suit the weight of the steel casting to be made, seemed to go to the root of the whole matter, and he quite agreed that the value of the sand-mixing department was at present more appreciated in certain steel foundries on the Continent than in England. Referring to the venting of moulds prepared from suitable sand, he was of opinion that it was possible to prepare in practice a mould from a facing mixture having a maximum permeability and crushing strength, which would require a minimum of venting. That did not mean, however, that venting could be dispensed with.

Replying to a question by Mr. Sillars, it was possible when testing an unknown sand under the blowpipe to identify faults arising from the presence of an excess of fluxing elements, such as iron, lime, soda, which would cause the material to fuse at a lower temperature than that at which the steel would be cast.

In reply to Dr. Hatfield's question, as to whether he could correlate the results of his blowpipe tests with the value of the sand, deducing therefrom how such materials would behave in a mould, he (Mr. Curtis) thought that the melting point of a sand did indicate how it would behave when used as a steel moulding sand, for if a sample of material during examination under the blowpipe fused at a certain temperature, it was obvious that it would be useless as a facing sand for steel poured at a higher temperature than that at which the sand fused. If Dr. Hatfield would submit samples of facing sands which, from his personal experience, had been known to give good results, and others which had given bad results when used for casting the same quality of steel, and by the same process, he (Mr. Curtis) would be pleased to examine and test them by his methods, with a view to ascertaining where the difference occurred.

With reference to Mr. Kayser's statement that Seger cones had not

a definite melting point, and were quite useless for calibration purposes, the author thought most makers of refractory materials were agreed that unit terms of high temperatures were relative and approximate, and, as he had already remarked, standard Seger cones were the most generally accepted media for judging high temperatures.

He (Mr. Curtis) realised that a radiation pyrometer could not be used with a blowpipe, as the black-body conditions on test-pieces employed would not lend themselves to use with such an instrument. Although he understood that certain photomicrographs of test-pieces were taken at exposure temperatures well within the range of a thermocouple pyrometer, it was not possible to apply that type of instrument to blowpipe conditions. He noted with interest that Mr. Kayser used a Davon super-microscope for observing surfaces of materials at high temperatures, but regretted he had not tried fusing mixtures made from Seger cones by the methods described in the paper.

He was sorry that the reproduction of the illustrations in his paper hardly did justice to the original photographs. Had Mr. Kayser seen the originals relating to samples Nos. 1311, 1315, 1313, and 1307, he would not have raised the point concerning the explanation of any lack of structure shown. The photomicrographs of those samples, however, did show that the sands in question presented far too dense a texture to justify their use as moulding sands without the addition of other materials, and a comparison of their texture and fusion points with those of sands Nos. 1301-2 and 3, known to produce good steel castings, would probably explain the point. It might, however, be observed that materials used in moulds for steel castings were hardly affected when exposed to temperatures lower than 1500°C .

Referring to Mr. Kayser's remarks on the relationship between the behaviour of a sample of steel moulding sand when exposed before the blowpipe and when exposed to the action of molten steel, the answer to Dr. Hatfield's remarks dealt with that point.

Mr. Curtis agreed with Mr. Kayser's statement that certain steels could be poured at higher temperatures than other steels in the same sand without "sand-stick." At present little information was available to explain those facts. It was well known, however, that mould surface fluxes composed of feldspar, potash, &c., would strip certain steel castings well, due probably to differences in contraction of the metal and the material forming the face of the mould, the latter at certain stages assuming a partial glaze.

In order to deal more fully with Mr. Kayser's criticisms, he had suggested that Mr. Kayser should submit two samples, each composed of pure silica, to one of which was to be added definite amounts of Fe_2O_3 , Na_2O , and K_2O , and to the other sufficient extra amounts of those materials to make the mixture fuse at a temperature 50°C . lower. On receiving the samples he would be pleased to test them for their fusion points in terms of Seger cones, and to make photomicrographs.

He was in entire agreement with Mr. Melmoth's remarks concerning

the effect of fluxes in facing sands used for producing light, medium, and heavy steel castings. It was true that chemical analysis might serve as a guide to the value of a sand, but the author did not altogether rely on that method, and he had therefore adopted the methods of test described. He was greatly pleased to note Mr. Melmoth's observations concerning variation in sands used for casting steel, and particularly the necessity for making daily routine tests, in order to maintain a reasonably consistent facing sand mixture. It was unfortunate that that procedure was not adopted in all British steel foundries.

He, however, could not agree that Mr. Melmoth's method for testing sands, by shaking a weighed quantity with a given volume of water, was accurate, as the clay substance in argillaceous sands could only be completely separated by prolonged boiling. With the apparatus described by the author, permeability tests could be carried out as quickly as the test suggested by Mr. Melmoth, but with much more accurate results, and far more information would be gained.

Mr. Melmoth, in his criticism of artificial steel facing mixtures, raised a very important point when he stated that moulds prepared from sands mixed with fireclay must be closed immediately, otherwise the face of the mould became friable and likely to cause a "wash." That was in accordance with his own experience, but Mr. Melmoth did not refer to the use of suitable organic "binders" for remedying that trouble with such mixture. By proper use and correct drying of the moulds that difficulty would, in his opinion, be overcome.

He was extremely pleased to learn that Mr. Melmoth had found by experience that clean used sand was a valuable constituent in a facing sand mixture. He had often found when examining sands under the blowpipe at high temperatures with the optical apparatus referred to, that facing mixtures containing clean used sand resisted, within limits, greater heats than mixtures of materials all new. It was, however, very necessary to eliminate dust from used sand, as it contained much flux, besides reducing the permeability. He could not agree that variation in sand was so great as to render data obtained from laboratory tests useless. Having made a very large number of tests, covering a wide range of samples over a period of several years, he could state without hesitation that it was possible to identify a "facing sand" and duplicate it, the artificial mixture varying but slightly from the original in permeability.

Mr. Searle's communication was of great interest as dealing with the paper from an entirely different point of view. Whilst noting that Mr. Searle had observed great variation in St. Erth sand, the author's experience was that such variation in argillaceous sand was not peculiar to St. Erth, but occurred in all deposits of argillaceous sand of Pliocene origin, particularly the Belgian varieties.

Turning to Mr. Searle's further remark, it was a fact that in certain steel foundries stable facing sand mixtures were being made from materials which could be procured economically, and such mixtures

showed very high permeability, high crushing strength, and produced clean steel castings of light and medium weights. He had found that given a certain facing mixture it was possible by his method of grading to split up the aggregate into specific sized groups, and from that to build up a similar mixture from other sands whose grain-sizes had been determined by similar methods. He was pleased that Mr. Searle referred to the necessity for adequately testing grain-size, permeability, strength, refractoriness, and composition of steel moulding sands, as hitherto that had not received the attention it deserved from steel founders.

He much regretted that Mr. Searle depreciated the value of blow-pipe tests, as in his own opinion the time saved, and ease with which such tests could be made, more than justified their use for the examination of small samples. It was unfortunate that the results obtained by Mr. Searle when using the oxygen blowpipe were unsatisfactory and misleading, but he felt that if Mr. Searle would repeat such experiments with the oxygen blowpipe and optical apparatus described in the paper, he would be convinced of the usefulness of such methods of test.

Mr. Searle appeared to over-estimate the author's faith in ultimate chemical analysis. He (Mr. Curtis) quite realised that chemical analysis for the purpose of comparing one isolated material with another of entirely different mineralogical composition was of limited value, but when comparing a range of materials having the same origin, he found that the constituents as determined by ultimate analysis gave a close indication of the relative values of each sample. It was from that point of view that he included in his paper the figures of ultimate analysis from the large range of samples of St. Erth sand dealt with. He agreed, however, that a mineralogical analysis would be invaluable when testing a range of materials of widely differing mineralogical composition.

Mr. Searle called attention to the fact that the discovery of any close relationship between the permeability and strength of a rammed mass of sand was not to have been expected. When conducting his researches he (Mr. Curtis) was unable to obtain proof that any tests had been carried out to show that no relationship existed between those two factors, and for that reason the tests referred to were made, with the results as shown. For the same reason tests were carried out with the object of finding out if any relationship existed between average grain-size and permeability, as he preferred not to accept any theory which he had not thoroughly investigated in practice.

It was gratifying to learn that Mr. Searle, although differing from him on several points, felt that the results of his experiments would be of great value to other research workers in the same field, and it would be correspondingly useful to Mr. Curtis if Mr. Searle and other research workers would publish the results of their experiments, as it was only by such comparative data that real progress could be made.

Iron and Steel Institute.

STRAIN DETECTION IN MILD STEEL BY
WASH COATING.¹

By R. S. JOHNSTON (ENGINEER PHYSICIST, U.S. BUREAU
OF STANDARDS, U.S.A.).

THE engineering and metallurgical professions are indebted to Messrs. Turner and Jevons for their interesting and valuable review and development of strain phenomena in steel.

The subject is one in which the author has been interested for a number of years, more especially, however, from the engineering standpoint. His experience in the testing of materials and constant study and observation of the Lüders-Hartmann lines phenomena, led him to the belief that while the effect became noticeable only after the development of the yield-point stress, the use of such phenomena offered valuable assistance in the study of stress distribution—or, at least, the coincident development of the yield-point stress, and the further development of such stress throughout the member as test loading continued.

In the ordinary procedure—that is, observation of the flaking of the mill scale—a large part of the real value of the method is lost, due to the fact that only the more pronounced lines are noticeable, and even these only under quite favourable lighting conditions. Further, the method that has been generally used for more precise work required polished specimens, and is therefore limited to small-sized samples.

In an endeavour to develop a more valuable method for observational purposes, especially for use on full-size structural forms, it has been found that a thin wash of white Portland cement offers decided advantages. By cleaning the structural section of oil and then coating the section with the cement-water wash by means of a soft bristle brush, results shown by the photographs on Plates XXXIV., XXXV. may be obtained.

¹ Published by permission of the Director of the Bureau of Standards of the U.S. Department of Commerce. (Being a further communication to the Discussion of the paper by T. Henry Turner and J. D. Jevons, *Journal of the Iron and Steel Institute*, 1925, No. I. p. 169.)

Figs. 1 and 2 are unretouched photographs of plate and angle column sections, 35 inches wide and 10 feet long, that were tested at the Bureau of Standards in an investigation of web buckling for the Delaware River Bridge Joint Commission. Fig. 3 is the result of a tension test of a riveted joint which failed by tearing of the plate through the first row of rivets. The difference in characteristic failure between a thin ($\frac{1}{2}$ inch) web plate, Fig. 1, and a thick ($1\frac{1}{2}$ inch) web plate, Fig. 2, as well as stress distribution between rivet rows, is shown by these figures.

The method permits of excellent photographic reproduction. It is, however, even more valuable, as it will distinctly show effects not ordinarily observable. Flaking will even occur about identification marks stamped in a plate, when they are in the section of larger stress, before any other section of the plate develops such strain lines. Small holes (No. 8 drill) cut in the plate to attach strain-indicating instruments will become the centre of strain effects, and show radiating strain lines before the remainder of the plate develops the corresponding stress. These smaller effects show distinctly with the cement-washed surface; on the unwashed plate they can be observed only by very careful inspection under favourable light conditions.

From the engineering standpoint the study of such phenomena gives reliable indications of the effects of details, &c., as is shown in connection with the rivet alignment in Fig. 2. The strain lines on Fig. 3 are also of interest when compared with Figs. 5 and 6 of Turner and Jevons' paper.

The author sincerely hopes that the work of Turner and Jevons will be continued, and that in future test programmes, especially on structural members, greater consideration will be given to similar studies of strain phenomena. It is his belief that such methods of analysis will furnish most valuable supplementary data on stress distribution. The method outlined here is applicable to full-sized structural shapes, and the development of Fry's method by Turner and Jevons offers a ready means for confirmation of any peculiarity developed in the wash-coating method. Neither method is difficult of application.

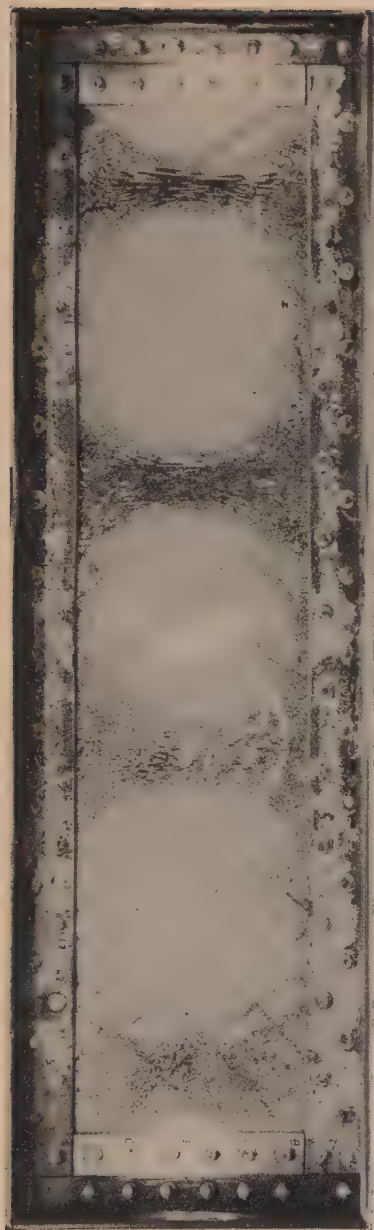


FIG. 1

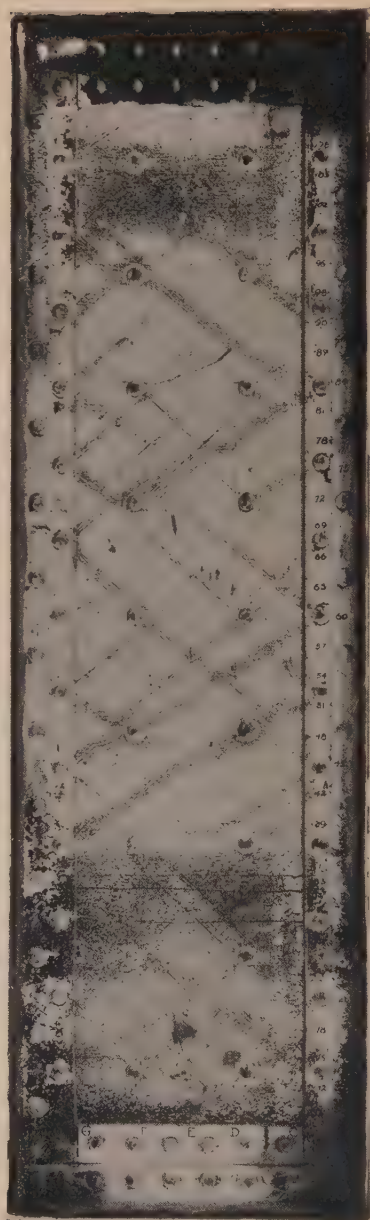


FIG. 2

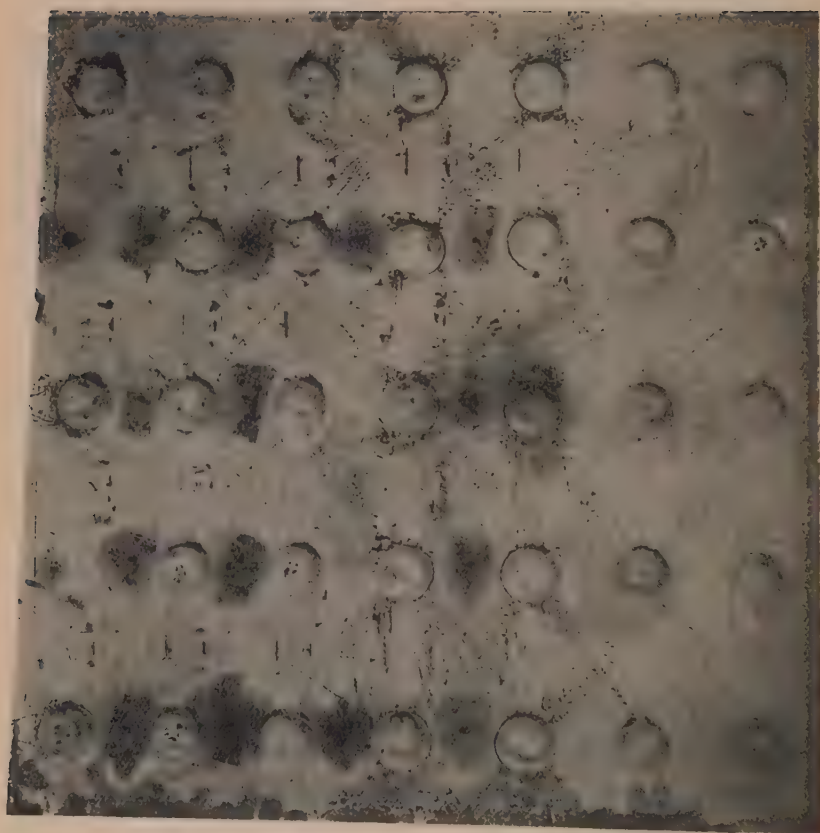


FIG. 3

CORRESPONDENCE.

Messrs. TURNER and JEVONS wrote in reply that they wished to thank Mr. R. S. Johnston for his interesting communication, which showed plainly that engineers might be able to obtain a rough indication of the strain distribution in large structures by simply painting them with a suitable cement wash. Such indications might be made more complete by etching, but the latter process could not easily be applied to such large structures as those referred to by Mr. Johnston; and furthermore, etching would damage the structure, whereas the cement wash would rather act as a protection. A suitable cement wash method might therefore be the practical complement to detailed scientific knowledge obtained in any other manner.

In their earlier work the authors had caused specimens to be coated with various metals electrolytically and by the metal spray process, and also with bakerlite, paints, varnishes, and cement, but they had obtained in that manner no satisfactory results, so far as strain detail indications in comparatively small specimens was concerned. Since the publication of their papers they had completed the examination of several new series of test-pieces, and they hoped to communicate the results of their observations in the near future. They much appreciated the encouragement given them by Mr. Johnston, and hoped that they would hear more of his work on large structures.

Iron and Steel Institute.

ON THE A2 LINE IN THE EQUILIBRIUM
DIAGRAM OF THE IRON-CARBON SYSTEM.BY KÔTARÔ HONDA.¹

In the equilibrium diagram of the iron-carbon system,² as given by the present writer, the A2 line is shown by a dotted

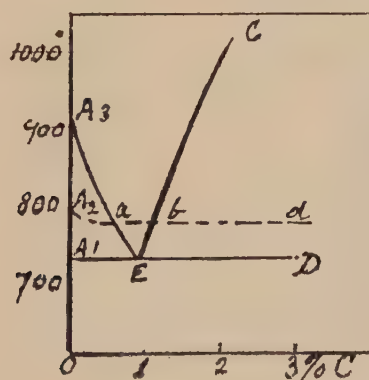


FIG. 1.

line to distinguish it from other lines or curves; the A2 point falls slightly at first, that is, from 790° to 770°, and then remains nearly constant, as shown in Fig. 1, and demonstrated by recent investigations made in the laboratories at Sendai.³ The A2 transformation in iron and steel is a continuous change extending from the lowest temperature up to the A2 point, not being in any way a change of phase.⁴ The A2 point as given in the diagram does not represent the temperature at which the transformation

¹ Received July 20, 1925.

² K. Honda, *Science Reports of the Tôhoku Imperial University*, 1922, vol. xi. p. 119; *Journal of the Iron and Steel Institute*, 1922, No. I. p. 381.

³ K. Honda and H. Takagi, *Science Reports of the Tôhoku Imperial University*, 1912, vol. i. p. 229; 1913, vol. ii. p. 203; K. Honda, *ibid.*, 1916, vol. v. p. 285; T. Ishiwara, *ibid.*, 1920, vol. ix. p. 401.

⁴ K. Honda, *Science Reports of the Tôhoku Imperial University*, 1915, vol. iv. p. 169; 1925, vol. xiii. p. 1.

takes place, but only the commencing temperature during cooling, or the final temperature during heating.

The A1 point or line represents of course a change of phase, abruptly taking place at a constant temperature. If these transformations are measured by magnetic analysis, the distinction between the A1 and A2 transformations is very clear, as seen

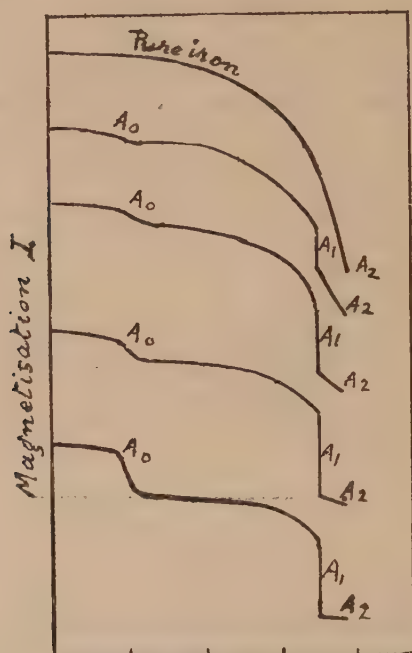


FIG. 2.

in Fig. 2.¹ Here, in order to avoid the overlapping of the curves, they are drawn displaced one above the other. The A0 and A1 transformations increase in magnitude, as the content of carbon increases. Beyond the A1 point, a weak magnetisation is actually observable for hypoeutectoid steels, and, contrary to the usual belief, even for hypereutectoid steels. This fact is also confirmed by the magnetic investigation made by Professor T. Ishiwara² with a very sensitive torsion balance. In the case of pure iron, at 800° C., and therefore above the A2 point, the intensity of mag-

¹ K. Honda, *Science Reports of the Tôhoku Imperial University*, 1916, vol. v. p. 285.

² T. Ishiwara, *loc. cit.*

netisation in a field of 10,000 gaussses amounts to 120 C.G.S. units, and in steels containing 0.7 to 1.0 per cent. carbon it amounts to 5 C.G.S. units in the austenitic region at the same temperature.

Theoretically considered, the A2 line may be divided into three parts—A2*a*, *ab*, *bd*. Portion *bd* represents the A2 point of the austenite of a concentration *b*—that is, the critical temperature at which the austenite changes from a weakly magnetic to a paramagnetic substance, and hence should be horizontal; in portion *ab*, the concentration of the austenite changes from

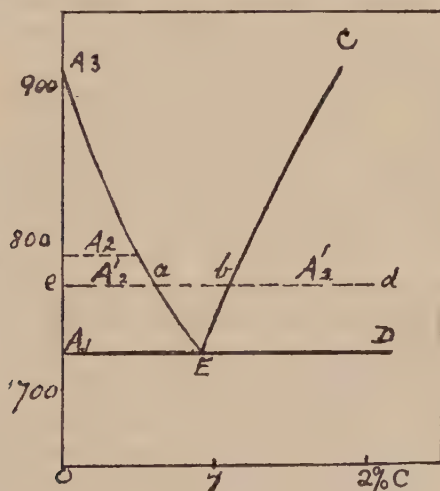


FIG. 3.

concentration *a* to *b*, but no appreciable variation of the A2 point is found. The steels having a concentration lying between A2 and point *a* consist of a mixture of ferrite and austenite of concentration *a*; hence, in a strict sense, the A2*a* line must consist of two horizontal lines a short distance apart of about 20°, as shown in Fig. 3. But as the pure ferrite is approached, its quantity increases at the expense of the austenite; on the other hand, as the austenite is approached, the quantity of ferrite decreases, while the austenite increases. The sensitivity of the magnetic or thermal analysis depends on the quantity of magnetic substance present, and, further, the difference of temperatures between the two horizontals is only 20°; consequently it is to

be concluded that it is not possible to observe these two horizontals separately by magnetic or thermal analysis, but that the A2 point appears to fall from a point A2 to line *ea* with a small addition of carbon to the ferrite, as is actually observed in experiments. Terminologically, it is therefore correct to call the upper horizontal the A2 line, and the lower one, including also two portions *ab* and *bd*, the A'2 line to distinguish it from the other. But these two lines, representing as they do no change of phase, must be rejected from the equilibrium diagram, which relates to the change of phase, or they may be introduced into the diagram as dotted lines without any connection with the lines representing the change of phase.

Lastly, the following question deserves notice. What are α - and γ -irons? According to the present writer, the most appropriate answer is as follows: The iron which has a body-centred cubic lattice is called the α -iron, and that which has a face-centred cubic lattice, the γ -iron. The usual expressions, such as " α -iron is magnetic" or " γ -iron is non-magnetic," do not fit the actually observed facts. For δ -iron which is formed at a temperature above 1400° is now known to be the same as α -iron, but it is not magnetic. Austenitic iron or steel is generally non-magnetic (or paramagnetic), but not always so; for, steels containing carbon in the vicinity of the eutectoid concentration are, as is shown above, slightly magnetic for some thirty degrees above the A1 point, that is, in the austenitic region.¹ Nickel and nickel-iron alloys containing more than 30 per cent. of nickel have also an austenitic structure—that is, their atoms assume a γ configuration, but they are all strongly magnetic at room temperature. In fact, magnetism is an atomic property and may therefore vary independently of the α or γ configuration of the iron atoms.

¹ See also Westgren and Phragmen, "X-Ray Studies on the Crystal Structure of Steel (Part II.)," *Journal of the Iron and Steel Institute*, 1924, No. 1. p. 159.

KEENAN: NOTES ON BLAST-FURNACE PRACTICE IN INDIA.

CORRESPONDENCE.

Mr. ERNEST BURY wrote that, in his view, the keynote of Mr. Keenan's work lay in the rapid production of carbon monoxide before the tuyeres, whereby oxidation of iron already reduced in the upper zones of the furnace was prevented. Iron so oxidized would require further coke consumption for its reduction.

Mr. Keenan represented the American school of blast-furnace practice, which aimed at the rapid production of carbon monoxide in two ways:

- (1) By grading the coke to a smaller size, whereby increased surface was offered for the reduction of the CO_2 initially formed to CO .
- (2) By designing furnace lines so as to secure rapid feed of such graded coke to the zone before the tuyeres, where oxidation would occur if the fuel feed were held up.

In short, American practice aimed at rapid production of CO by increased coke surface and rapid feed of coke to the tuyeres.

Much thought was now being expended upon the reactivity of coke—in other words, its solubility in CO_2 in order to obtain the results achieved by Mr. Keenan by furnace construction and fuel grading. The line taken by the reactivists was praiseworthy, for the reason that if the reactivity of coke could be increased by artificial means without loss of mechanical strength the scrapping of much blast-furnace capital in Great Britain in competition with the practice of other countries would be avoided. The difficulty, however, in that connection was that highly reactive cokes were mechanically soft. It remained to be proved whether artificial means would remedy that defect. In the light of present-day knowledge was it preferable to develop on proved lines or to cling to a theory?

Mr. J. L. KEENAN replied, in answer to the question of Mr. Evans regarding the "rotation of filling," that he had in mind the various ways in which the raw materials could be charged to get the desired results. As the large bell was of sufficient capacity to hold 15,000 lbs. of coke, the size of the coke unit, it was possible to charge as follows:

Charge 15,000 lbs. coke on bell and dump it;
then charge 23,500 lbs. ore + flux on bell; dump.

One could readily see that such procedure would cause the fuel to form thick layers in the furnace, with a corresponding comparatively thick

layer of ore and flux. To obtain thinner layers all that was necessary was to break the charge in half, but best results were obtained by charging as follows :

Charge 7500 lbs. coke + $\frac{1}{2}$ ore + $\frac{1}{2}$ flux on bell ; dump ;
charge 7500 lbs. coke on bell ; dump ;
charge $\frac{1}{2}$ ore + $\frac{1}{2}$ flux on bell ; dump.

The ore and flux charged in the first half-charge would obviously spread out over the coke.

When the bell started to lower, the coke fell first ; as the ore gained in velocity it hit against the side of the furnace and rolled down toward the centre. The ore dumped during the latter half of the charge tended to remain along the outside of the layer, giving a better distribution. The author did not think that the life of the new furnaces would be any shorter. Both " C " and " D " were in good condition at present, and every indication pointed to a longer life than had been obtained on " A " and " B. " The coke breeze was screened out with $1\frac{1}{8}$ -inch screens.

Mr. Hutchinson asked whether the total output of iron for the life of the new furnaces had increased. The author had no exact figures with him at present, but he knew that " D " furnace had already produced a larger tonnage during its present life of approximately two years and ten months than the older furnaces produced in their entire life, and " D " furnace still showed no signs of requiring repairs.

In answer to Mr. Sillars, he did not know the exact figure for the percentage of error. As far as the charging was concerned, the ore and stone were weighed in a lorry car, the scales being checked daily. The blast was delivered by turbo-blowers, which were corrected for temperature and pressure : 5 per cent. would cover the margin of error there. The error was checked from time to time from the weight of coke and ore charged, and the oxygen derived from that ore over a week's run. The author did not agree that a change of only a few inches could be made with any certainty in the light of modern construction. Quite recently a certain furnace which had a 17-foot diameter hearth was blown out for repairs. The furnace company ordered new material to equip that particular furnace with a hearth 18 feet 6 inches in diameter. A few days before the installation of the new hearth the company scrapped the new hearth and held up repairs until material for a 20-foot hearth arrived. They made a change of 3 feet, not 3 inches, and have not regretted it.

The author recently visited a plant where a furnace was producing 670 tons of iron a day on 2400 lbs. of coke per ton of pig iron. The slag made was 2300 lbs. The iron content of the ore used averaged 35 per cent. That furnace had a 20-foot hearth. At another plant he noticed that the hearth diameter of 20 feet, which might be taken as a former limit, had been increased to 21 feet 6 inches. The bosh was lowered to 8 feet 3 inches, which certainly was, he believed, a new low level. That company had no precedent to rely on when they increased

their hearth diameter 18 inches and lowered the top of the bosh from 10 feet to 8 feet 3 inches. That furnace was giving results which more than realised the expectations of those concerned.

In the light of modern construction one could safely say that a "few inches" was a rather too conservative figure.

Professor Louis desired to know the number and size of the tuyeres. "C" and "D" furnaces had twelve tuyeres each: 5 inch and 6 inch diameter tuyeres were used, their lengths being 12 or 15 inches, as conditions warranted. The tuyere line was 1 ft. 10 inches below the bottom of the bosh. The furnaces drove faster and produced larger tonnages in the dry weather than during the monsoons. That situation could be relieved by drying the blast, and they were at present thinking along those lines, now that a much cheaper method of doing so had been proved feasible.

The author was sorry he could not supply Mr. Wood with an analysis of the coke ash. The silica in the ash usually ran about 50 per cent. to 52 per cent., FeO 3 per cent., $\text{CaO} + \text{MgO}$ 0.3 per cent.

VISITS AND EXCURSIONS AT THE AUTUMN MEETING AT BIRMINGHAM.

THE Autumn Meeting of the Iron and Steel Institute was held in Birmingham on September 9, 10, and 11, 1925, an influential General Reception Committee having been formed for the purpose of making the necessary arrangements for receiving and entertaining the members.

GENERAL RECEPTION COMMITTEE.

The Chairman was Mr. George Hatton, C.B.E., Member of Council ; Professor Thomas Turner, M.Sc., Dean of the Faculty of Science, University of Birmingham, Member of Council, was Vice-Chairman ; Mr. J. Payton, Past-President of the Staffordshire Iron and Steel Institute, acted as Hon. Treasurer ; and Mr. H. B. Jacks, President of the Staffordshire Iron and Steel Institute, and Hon. Member of Council, undertook the duties of Local Hon. Secretary. The thanks of the Council and Members are due to these gentlemen, and especially to Mr. Jacks, for the time and care which they devoted to the work of organisation preceding and during the meeting. The great success of the meeting was due to their unremitting labour in carrying out every detail with the most minute regard for the comfort, convenience, and enjoyment of the members and their ladies.

The constitution of the Executive Committee was as follows : Mr. George Hatton, C.B.E., Managing Director, Earl of Dudley's Round Oak Works, Chairman ; Professor Thomas Turner, M.Sc., Dean of the Faculty of Science, Birmingham University, Vice-Chairman ; Mr. Joseph Payton, Hon. Treasurer ; Dr. L. Aitchison ; Mr. H. A. Davies ; Dr. J. N. Friend ; Mr. J. W. Hall ; Mr. D. H. Ingall ; Mr. T. Jenkins ; Mr. H. M. Jenks ; Dr. F. Johnson ; Mr. P. Jump ; Mr. Isaac E. Lester ; Colonel A. McBean ; Mr. A. R. Page ; Mr. T. S. Peacock ; Mr. F. Scarf ; Mr. H. Silvester ; Captain F. Somers, O.B.E. ; Colonel J. S. Trinham ; Mr. A. J. While ; and Mr. H. B. Jacks, Hon. Secretary.

The following sub-committees were appointed to organise the sectional arrangements :

Finance Committee.

HATTON, G.	PAYTON, J.
JENKS, H. M.	SCARF, F.
LESTER, I. E.	TURNER, Professor T.
MCBEAN, Colonel A.	

Visits Committee.

AITCHISON, Dr. L.	LESTER, I. E.
DAVIES, H. A.	PAGE, A. R.
HALL, J. W.	SOMERS, Captain F.
HATTON, G.	TURNER, Professor T.
JOHNSON, Dr. F.	

Entertainments Committee.

HATTON, G.	SILVESTER, H.
INGALL, D. H.	SOMERS, Captain F.
JENKS, H. M.	TRINHAM, Colonel J. S.
JUMP, P.	TURNER, Professor T.
JOHNSON, Dr. F.	WHILE, A. J.
PAGE, A. R.	

The Secretaries' Office was situated in the University, Edmund Street, Birmingham, formerly known as Mason's College of Science, and by kind permission of the Council of the University, the General Meetings were held in the Lecture Theatre of the same building. The proceedings opened at 10 A.M. on Wednesday, September 9, and the Lord Mayor of Birmingham, Mr. Alderman Percival Bower, attended and welcomed the President, Sir Frederick Mills, Bart., Council and Members to the City of Birmingham. Colonel H. E. Parkes, President of the Birmingham Chamber of Commerce, was also present in support of the Lord Mayor. An official account of the proceedings will be found elsewhere, but occasion may be taken here to endorse the expression of thanks to the Lord Mayor for his kind words of welcome and for the warm interest displayed by the Lord Mayor and Lady Mayoress in the arrangements for the meeting.

The meeting adjourned at 12.30 P.M., and members and ladies accompanying them then proceeded to the Grand Hotel, where the whole party was entertained to luncheon by the General Reception Committee, Mr. George Hatton, Chairman, presiding. After luncheon Mr. Hatton welcomed the members again on behalf of the Reception Committee and proposed the health of Sir

Frederick Mills, Bart., President, who replied in a few words thanking Mr. Hatton and his Committee for the generous and hospitable reception accorded to the visitors and their friends.

Immediately after luncheon the party broke up and divided into several groups, which were separately conveyed to the works of the following companies: (1) Messrs. Austin Motor Co., Ltd., Northfield; (2) Messrs. Bromford, Ltd., Aston; (3) Messrs. B.S.A. Tools, Ltd., Sparkbrook; (4) Messrs. Elkington & Co.; (5) Messrs. Kynoch, Ltd., Witton; (6) Messrs. Henry Wiggin & Co., Ltd.; (7) Messrs. Wolseley Motors, Ltd., Adderley Park; (8) Messrs. Belliss and Morcom, Ltd.; (9) Messrs. Hughes-Johnson Stampings, Ltd., Langley Green; (10) Messrs. J. Gillott and Sons, Penmakers; and (11) Messrs. Cadbury Bros., Bournville. It should be mentioned that Messrs. Cadbury's had already received a party earlier in the day at their works, whither the ladies had been specially invited.

At all the works the members were received by the directors and members of the staffs, and under their guidance spent the afternoon in going through the various departments, after which they were entertained to tea.

In the evening a reception was held by the Lord Mayor and Lady Mayoress at the Council House and Art Galleries. There was a large assembly, and an enjoyable programme of music was performed by Mr. Joseph H. Riley's Band. The reception was followed by dancing in the Great Hall of the Council House.

The business sessions were resumed on the morning of September 10, and the meeting closed at 12.40 P.M., at which hour motor vehicles were in attendance to convey parties to visit the works of the following firms: (1) Messrs. W. and T. Avery, Ltd., Soho Foundry; (2) Messrs. B.S.A. Ltd., Small Heath; (3) Messrs. The General Electric Co., Ltd., Witton; (4) Messrs. F. H. Lloyd & Co., Ltd., Wednesbury; (5) Messrs. Walter Somers, Ltd., Halesowen.

On arrival at the works the members of the respective parties were hospitably entertained to lunch, after which they were conducted round the establishments, and saw much that was interesting and instructive. The hosts then invited their guests to tea, and the parties returned to their hotels about 5.30 P.M.

In the evening the visitors were invited to a Reception and *Conversazione* at the University, at Edgbaston. The guests were received by the Vice-Chancellor, Sir Gilbert Barling, Bart., and Miss Barling, Principal C. Grant Robertson, M.A., C.V.O., and Professor Thomas Turner, M.Sc., Dean of the Faculty of Science. Dancing took place in the Drawing Office, which had been tastefully decorated and turned into a delightful ballroom. The various departments, in which a number of exhibits had been arranged, were open for inspection by the members. In the Metallurgical Department the exhibit arranged by Professor Thomas Turner included metallurgical specimens, and theses and published papers dealing with researches in many branches of ferrous and non-ferrous metallurgy. In the Civil Engineering Department, the exhibits included as a feature of special interest the 300-ton horizontal testing machine for making tension, compression, and bending tests on full-size structural members up to 30 feet in length. Exhibits were also shown in the Departments of Mechanical Engineering, Mining, and Geology. The University possesses a Faculty of Commerce, established in Edmund Street in 1901, and removed to Edgbaston in 1919. Among the courses taken by its students is one embracing a considerable amount of applied science. It is thus possible to acquire a combined knowledge of economics and science, which is so essential for those seeking responsible positions on the commercial side of modern industry.

On Friday the 11th about 105 members and ladies took part in an excursion to Kenilworth, Guy's Cliffe, Warwick, and Stratford-on-Avon. Motor vehicles were in readiness at 9.15 A.M., and the visitors, under the guidance of the Local Reception Committee, first visited Kenilworth, and were shown over the ruins of Kenilworth Castle. A short drive thence brought them to Guy's Cliffe, where they enjoyed the privilege of seeing the beautiful grounds and the old mill. They then proceeded to Warwick, where some time was spent in a most interesting visit to the Castle. After being shown round the principal rooms the visitors assembled for lunch at the Woolpack Hotel, Mr. George Hatton presiding. At the end of the lunch, in response to a proposal by Mr. Hatton, a most cordial vote of thanks was passed to Mr. H. B. Jacks, for the skilful manner in which he had carried

out the work of organising the meeting, and for his many kind attentions to the visiting members. The party then travelled on to Stratford-on-Avon, where Shakespeare's birthplace, the Memorial Theatre, Holy Trinity Church, and other places of interest were visited. Tea was afterwards served at the Shakespeare Café, after which the visitors returned direct to Birmingham.

OBITUARY.

HERBERT BATES, O.B.E., died at his residence in Manchester on October 17, 1925, at the age of fifty-one. He served his apprenticeship with the firm of Hulse, machine tool builders, Salford, at the time when his father was managing director. At the age of eighteen he was successful in winning a Whitworth Exhibition. He succeeded his father as managing director of the same firm, and held that position until the time of his death. During the war Messrs. Hulse's works were taken over by the Admiralty, and in recognition of the services which Mr. Bates rendered to the Government he received the Order of Officer of the British Empire.

Mr. Bates was elected a member of the Iron and Steel Institute in 1904.

Professor EDWARD DEMILLE CAMPBELL, whose death occurred at Ann Arbor, Michigan, on September 18, was born in Detroit, Michigan, in 1863, and was the youngest of the three sons of Judge James V. Campbell, a member of Michigan's first and most famous Supreme Court. He received his university training at the University of Michigan, graduating from that institution in 1886. For four years thereafter he worked with three coal and iron companies as technical chemist, and was called back to his Alma Mater in 1890 to become assistant professor of metallurgy. From that time until his death he remained in that university, his title changing numerous times as the growth in the number of students and staff required adjustments. In 1902 he organised the Department of Chemical Engineering, and in 1905 was appointed Director of the Chemical Laboratory, which latter position he held up to the time of his death.

On April 12, 1892, while working on a problem concerning the identification of the hydrocarbon gases evolved during the solution of a steel which had been subjected to specific heat treatment, a violent explosion occurred, which resulted in total blindness to Professor Campbell. Ten days later he was back in the university, conducting his classes and supervising laboratory work. In his later years he gave up lecturing and spent most of his time directing research, conducting reading classes, and attending to his administrative duties as director of the laboratory. Each year an advanced student in chemistry worked with him as his private assistant, and the benefit received from such constant contact with him may be judged by the fact that the greater number of those assistants are now filling important positions in the industrial world.

Professor Campbell's contributions to scientific literature number seventy-seven papers; those in his early years of work dealt with Portland cement and problems in analytical chemistry, while later his attention was directed to the correlation of the chemical and physical properties of steel, regarding which he wrote about forty original articles, of which twenty were contributed to the Iron and Steel Institute.

Professor Campbell was elected a member of the Iron and Steel Institute in 1905. He was also a member of the Faraday Society, the American Chemical Society, the Washington Academy of Sciences, and Tau Beta Pi, and an honorary member of the American Society for Steel Treating. He was an ardent Rotarian, seldom missing the weekly luncheons of that club, and was also much interested in the Research Club of the University of Michigan, of which he was president during one year.

Baron EVENCE COPPÉE was born in 1851, and after a brilliant scholastic career he took his degrees in Arts, Mining Engineering, and Civil Engineering in 1872 at the University of Louvain.

He was the son of M. Evence Dieudonné Coppée, the inventor of the closed retort coke-oven, which about 1850 created a revolution in the coking industry. These ovens rapidly took the place of the old beehive ovens, and all the modern types of coke-ovens have evolved from this closed-retort oven. On succeeding to his father's business when quite a young man, Baron Coppée devoted himself to the coke-oven industry, and was responsible for the many developments which have sprung from the first Coppée oven, and which are still being built in countries where the recovery of by-products is of no advantage.

It is interesting to note that Baron Coppée's father started a plant of Coppée retort ovens in 1850 at Haine St. Pierre, Belgium, which is still the property of the Coppée family. The original battery has been replaced by more modern ones as one improvement succeeded another, and it is expected that the latest type of high temperature, large output ovens built of silica brick will shortly be started there.

At the end of the last century Baron Coppée participated very vigorously in the by-product industry, and became not only interested financially in many plants, but was the actual owner of numerous by-product coking installations. At the time of his death he was, in fact, the principal producer of coke and by-products in Belgium. Realising the great saving to be effected by the proper treatment of coals, he devoted much time to the development of the coal-washing industry which his father had begun to study about 1858, and in this connection again Baron Coppée became known as one of the most important constructors of coal-washeries on the Continent. During the years 1886 to 1910 he acquired successively the collieries of Ressaix, Leval, Peronnes, Mont St. Aldegonde, and Houssu (Belgium), which he amalgamated into one company under his control, and of which the production at

present is about 1,400,000 tons of coal, 300,000 tons of coke, and 50,000 tons of patent fuel per annum.

In later life he became the pioneer of what is to-day one of the commercial hopes of Belgium, namely, the development of the new coalfield of Limbourg en Campine. His Colliery Company at Ressaix and Messrs. Schneider's Company at Le Creusot (France) formed a new company known as the Charbonnages de Winterslag for the exploitation of the coal concessions in Campine. The output of the new colliery, which is undoubtedly one of the best equipped on the Continent at present, is about 700,000 tons per annum.

Besides promoting other colliery undertakings, he was interested in steel production, banking business, and the shipping industry, so that it may be said of him that he played an important part in the economic development of Belgium. He had some interest likewise in mining affairs in Great Britain, and in the development of the by-product industry in that country. For the great part which he played in the industrial world of Belgium, he was created a Baron by King Albert in 1912.

As President of one of the sectional Associations of Colliery Owners in Belgium, he became during the war the President of the Federation of Coal Owners' Associations in Belgium. In this position it fell to him to take certain measures in accord with the Belgian Government, then at Havre, who decided the course of economic policy during the occupation of the country by the Germans. It was this policy which involved Baron Coppée in the famous case known as the "Affaire Coppée" on the Continent, which case terminated entirely in his favour.

He is succeeded by his son, the present Baron Coppée, who is forty-two years of age, and has for the last twenty years taken an active part in the business. Baron Evence Coppée was elected a member of the Iron and Steel Institute in 1887.

THOMAS HENRY FIRTH died suddenly at his residence in Sheffield on July 16, 1925. Mr. Firth, who was fifty-four years of age, was chairman of the Brightside Foundry and Engineering Co., Ltd., and allied companies. He received his early education at the Central Secondary School, Sheffield, and entered Firth College, now incorporated with Sheffield University. He studied engineering under Professor Ripper, chemistry under the late Professor O'Shea, and metallurgy under Professor Arnold. On finishing his training, Mr. Firth became manager of the works of Messrs. J. C. and J. S. Ellis, Ltd., and when that undertaking was amalgamated with the Brightside Foundry and Engineering Co., he was appointed assistant managing director of the larger firm. In 1915 he was appointed a member of a committee formed by the Government for the purpose of increasing the output of the various metallurgical industries engaged in the production of war material. In that capacity he performed much useful work. Mr.

Firth also took a prominent part in the activities, both local and national, of the Employers' Federation. For several years he was a member of the Sheffield City Council, and was elected to several important committees, among them the Electric Supply Committee. In addition to his other activities, Mr. Firth devoted much spare time to the formation and organisation of sports' clubs.

Mr. Firth was elected a member of the Iron and Steel Institute in 1905. In 1918 he was President of the Institute of British Foundrymen.

WILFRED WILSON HOLLINGS died on June 17, 1925. He received his training at Birmingham University—then Masons' College. On completion of his education in 1902 he became associated with the Brymbo Steel Co., Ltd., and spent several years in acquiring experience in basic open-hearth practice. During the eight years from 1902–1910 in pursuit of this object he visited the United States, Belgium, and Germany, and studied steel-making practice in those countries. Unfortunately in 1910 his health broke down, and in consequence of illness he was unable during the next ten years to fill any executive position. In the interval he devoted himself to the study of the theoretical side of blast-furnace practice. His interest had been strongly aroused by James Gayley's paper on "The Use of Dry Blast," published in 1904, and some years later he began to plan the carrying out of a series of experiments and observations on the heat balances of modern blast-furnaces, but his health again broke down before he was able to put his plan into execution. Mr. Hollings was the author of a paper on "Variations in the Heat Supplied to the Blast-Furnace, and their Effect on Fuel Consumption," read before the Iron and Steel Institute at the Cardiff Meeting in 1920. He was elected a member of the Iron and Steel Institute in the same year.

WILLIAM UPRICHARD JACKSON of Tettenhall, Wolverhampton, died on July 19, 1925, at the age of fifty-three years. Mr. Jackson became managing director of the Weldless Steel Tube Co., Ltd., in 1899, and was elected chairman of the Company in 1920, on the death of Mr. F. Z. Lloyd. For reasons of health he retired from both these positions in 1924. Mr. Jackson was elected a member of the Iron and Steel Institute in 1913. He took a considerable interest in the organisation of the Autumn Meeting held at Birmingham in 1925, and was a member of the Local Reception Committee.

WILLIAM MCCONWAY died at Pittsburgh, U.S.A., on July 28, 1925. Mr. McConway was born in Desertmartin, Co. Derry, Ireland, in 1842, and emigrated to the United States with his parents at the age of seven. His parents settled in Pittsburgh, and the boy attended school until the age of twelve, and was then put to work at the Old Novelty Ironworks. After six months with that firm he obtained employment with

Olnhausen and Crawford, a pioneer steel manufacturing company, and remained with them until the outbreak of the Civil War, when he enlisted as a private in the Pennsylvania Volunteers. In 1863 he obtained a commission as 2nd Lieutenant. After receiving his discharge he rejoined his firm, and was admitted to partnership in 1866. In 1869 he promoted the firm of Lewis & Co., predecessors of the McConway and Torley Co. By the members of the Institute McConway will be best remembered on account of his interesting film demonstration during the meeting of the Institute in York in 1922, on which occasion he described his new process for the production of steel discs in a centrifugal hydraulic casting machine in which, due to the rapid rotation of the cylinder, the metal is forced against the cylinder wall and forms a cylindrical or ring-shaped ingot.

Mr. McConway was elected a member of the Iron and Steel Institute in 1890. He was a trustee of the Carnegie Institutè and the Carnegie Institute of Technology.

Captain MATHEW PHINEAS HENRY RIAL SANKEY, R.E., C.B., C.B.E., died at his residence in Ealing on October 3, 1925. He was born at Nenagh, Co. Tipperary, on November 9, 1853, and received his early education in Switzerland, subsequently passing through Woolwich and Chatham, and securing his commission in the Royal Engineers in 1873. During his term of instruction at the School of Military Engineering at Chatham he was lent by the War Office to assist at the famous Continuous Brake Trials, which took place on the Lincoln branch of the Midland Railway in 1875. Subsequently, he was engaged in the office of the late Mr. Edward Woods on calculations connected with those trials. From 1876 to 1882 he was employed in succession at the War Office (Designs Branch); at Manchester, where he was in charge of the Royal Engineers drawing office; at Gibraltar, in charge of the Military Telegraphs and Signal Station; and at Kingston, Canada, as Instructor in Fortification and Geometrical Drawing at the Royal Military College, which had just been started. In 1882 he was recalled from Canada to take up duties at the Ordnance Survey, Southampton. Here he came into touch with a technical problem which led to a complete change of vocation. The electrolytic process discovered in 1839 by Spencer and Jordan was in use at Southampton for the duplication of engraved plates, the Smee cell being used to provide the current. An Elmore low-voltage dynamo had been bought by the War Office, but could not be worked successfully. Lieutenant Sankey was directed to continue the tests, and his problem was to find an engine which would drive the dynamo steadily enough to produce a constant current. He decided that the high-speed type would be best for the purpose, and he eventually purchased a Willans three-throw engine and achieved success. It was through the purchase of this 6-h.p. high-speed engine that Captain Sankey made the acquaintance of Mr. Willans, whom he joined in 1889. In 1892 Mr. Willans was

killed as the result of an accident, and responsibility for the design of the engines, and later of the turbines, built by the firm fell upon Captain Sankey. Under his direction the firm removed from Thames Ditton, and the new works were laid out at Rugby.

In 1904 he severed his connection with Messrs. Willans and Robinson, and began practice as a consulting engineer in London. During the war Captain Sankey was honorary Engineering Adviser to the Director of Fortifications and Works, in which capacity he performed services of great value. He was concerned among other things with the repair of machinery used by the Royal Artillery, the Royal Army Service Corps, and the Tank Corps. He also did important work as one of the engineers on the Honorary Valuation Committee.

Captain Sankey was for many years a Member of Council of the Institute of Mechanical Engineers, and became President in 1920-1921. He was also a Vice-President of the Institution of Civil Engineers. He was a member of the Institution of Electrical Engineers, Naval Architects, Gas Engineers, and the American Society of Mechanical Engineers, and for some years he served on the Governing Board of the National Physical Laboratory. He was elected a member of the Iron and Steel Institute in 1913.



SECTION II.

*NOTES ON THE
PROGRESS OF THE HOME AND FOREIGN
IRON AND STEEL INDUSTRIES.*

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The Editor has been assisted in the preparation of these Notes by R. ELSDON, Librarian, and A. E. CHATTIN, Assistant Secretary of the Institute,

IRON ORES

AND OTHER METALLIFEROUS ORES USED IN THE IRON AND STEEL INDUSTRY.

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I.—GEOGRAPHICAL DISTRIBUTION OF ORES.

(Arranged in alphabetical order under Countries.)

Australia.—H. G. Raggatt, *Chromium, Cobalt, Nickel, Titanium, Thorium, Cerium* (New South Wales Geological Survey, 1925, Bulletin No. 13). Brief information is given dealing with the distribution and uses of these minerals in New South Wales.

The Balkans.—D. A. Wray, *Mineral Resources of Albania and Macedonia* (Mining Magazine, June 1925, p. 329). The minerals mentioned as occurring in considerable quantities include asbestos, bauxite, magnesite, platinum, gold, and silver. Other occurrences referred to are those of iron, copper, lead, zinc, manganese ore, chromium ore, coal, and indications of petroleum.

Canada.—W. A. Parks, *The Mineral Resources of Northern Ontario* (Proceedings of the Royal Society of Arts, Aug. 21, 1925, vol. 73, pp. 898–915). A general review of the mineral wealth of Ontario. The principal metals produced are silver, nickel, gold, iron, copper, cobalt, as well as others, such as the platinum metals, lead, zinc, &c., in smaller amounts. Among the minerals that are produced may be included graphite, mica, asbestos, apatites, molybdenite, feldspar, marble, corundum, talc, barite, fluorspar, and garnet. The mineral wealth of Ontario is truly immense, and there are huge tracts which are still undeveloped. The author considers that the plain bordering Hudson Bay will one day supply peat in enormous quantities, but the amount is not yet estimated. Reference is made to Sir William Logan, the "Father of Canadian Geology."

China.—C. Y. Wang, *Bibliography of the Mineral Wealth of China* (Reprinted from the Journal of the Association of Chinese and American Engineers, 1925, vol. 6, No. 5). This bibliography forms a continuation of the author's previous work, and covers the period 1918 to 1924. It is divided into the following sections: Coal, iron, minerals in general, mining industry in general, Japanese publications.

C. C. Liu and J. C. Chao, *Preliminary Report on the Geology and Mineral Resources of Kiangsu* (Geological Survey of China, Peking, 1924). Brief particulars are given of the Feng Huang Shan iron ore deposits, the most important in Kiangsu, which are situated near Nanking.

T. O. Chu and C. Li, *Geology and Ore Deposits of Ching Hsing District, Chihli Province* (Bulletin of the Geological Survey of China, Dec. 1924, No. 6, pp. 37–50). A brief account is included of the coal-fields and iron ore deposits in this province.

England and Wales.—A. F. Hallimond, *Iron Ores: Bedded Ores of England and Wales, Petrography and Chemistry* (Memoirs of the Geological Survey: Special Reports on the Mineral Resources of Great Britain, 1925, vol. 29). The microstructure and mineral composition of the English bedded ores are described. A series of analyses was made for the determination of the oolites, and of the carbonates and green silicates in the ground-mass. Detailed descriptions are given of the Cleveland and Northants ironstones, the Marlstone, Carboniferous, and minor bedded ores, which are arranged according to their petrography. The physical and chemical conditions under which the ironstones were formed are reviewed. The reactions that occur during weathering, and their bearing on the question of secondary enrichment, are also considered. The report includes a number of photomicrographs showing typical structures. In an appendix F. R. Ennos and R. Sutcliffe describe the method used in estimating the chlorite in sedimentary rocks by extraction with dilute hydrochloric acid.

Germany.—R. Seemann, *The Geological Conditions along the Amberg-Sulzbach and Auerbach-Pegnitz Fault* (Abhandlungen der Naturhistorischen Gesellschaft, Nürnberg, 1925, vol. 22, pp. 91–151; Zeitschrift für Praktische Geologie, June 1925, vol. 33, p. 104). The iron ores extend on the surface over an area 70 kilometres long and about 5 to 10 kilometres in width; the ores are mainly of four kinds: sedimentary, carbonate, limonite formed by oxidation of the carbonate ores, and metasomatic ores (*Felsenerz*). The last named is the best grade, containing: iron 45, manganese 0.8, and phosphorus 0.27 per cent. The thickness of the deposit varies greatly, the substrata being very much broken.

Philippine Islands.—H. Nishihara, *Mineral Reconnaissance in the Philippines* (Engineering and Mining Journal-Press, May 2, 1925,

vol. 119, pp. 717-724). The author refers to the iron ore deposits of the Philippines, which are comparatively small but appear to contain ore of good quality. The most important is in the Camarines Province on the island of Luzon, and near Mambulao. The main ore body forms the backbone of the Larup Peninsula and extends farther north to Calambayanga Island. Outcrops of iron ore can be traced in a fairly well-defined continuous line for about 4500 feet. The ore is non-crystalline and porous near the surface. The thickness exposed appears to average about 12 feet. An average of thirty-two samples gave the following percentage composition: iron, 63.89; silica, 1.78; alumina, 6.30; phosphorus, 0.14; sulphur, 0.06; water, 9.27; manganese, 0.31 per cent. A rough estimate of the amount of ore in sight is 600,000 tons at Larup, and a further 138,000 tons on Calambayanga Island. No development of this deposit has yet been attempted. In Marinduque Island, about 10 miles inland from Maopog on the west coast, is a deposit of magnetite, of which there are exposed about forty large rounded water-worn blocks, some 40 feet in diameter. Mention is also made of a manganese ore deposit about $5\frac{1}{2}$ miles from Aroroy on Masbate Island, and not far from the Colorado and Syndicate Gold Mines. The deposit is about 10 feet thick. Average analyses of samples taken from three different claims show: manganese 47.95 to 50.26, and silica 14.19 to 13.81 per cent., indicating that the manganese mineral is probably braunite.

Spain.—L. Barreiro, *Iron Ore from Northern Spain* (Iron Age, Sept. 10, 1925, vol. 116, pp. 680-683). An account is given of the character and extent of the iron ore deposits of Vizcaya, their method of working and labour conditions.

United States.—D. MacVichie, *Iron Fields of the Iron Springs and Pinto Mining Districts, Iron County, Utah* (Paper read before the American Institute of Mining and Metallurgical Engineers, Sept. 1925). Brief particulars are given of the chief deposits in this region.

Mineral Resources of the World.—M. Fourment, *The World's Mineral Resources* (Part V.) (Revue de Métallurgie, Mémoires, Mar. 1925, vol. 22, pp. 170-178). A continuation of the discussion of the supply and development of the chief metalliferous deposits of the world, based, as in the case of the previous instalments, on the monographs issued by the Imperial Mineral Resources Bureau, London. The present article is an abstract of the bulletin relating to tungsten. Chromium resources are dealt with in a later article (ibid., May 1925, pp. 302-309).

Chromium (Mining Journal, Sept. 5, 1925, vol. 150, pp. 692-693). A brief outline of the many uses to which chromium is put, and a summary of the present sources of the metal and the prospects of future supplies.

The Manganese Ore Situation (Mining Journal, July 4, 1925, vol. 150, pp. 535-536). A review of the sources of manganese ores and their uses.

B. D. Saklatwalla, *Vanadium, a Chemical Curiosity put to Use (Research Narratives)* (Blast-Furnace and Steel Plant, May 1925, vol. 13, pp. 194, 202). A short account of the history of vanadium and its development from a rare element to an important ingredient of commercial alloys.

II.—PREPARATION OF ORES.

Flotation of Minerals.—H. Schranz, *The Flotation Process for Treatment of Coal and Ores* (Kruppsche Monatshefte, Apr. 1925, vol. 6, pp. 57-64). The principles on which the flotation process operates are discussed. In applying the process to the washing of coal or to the separation of ore the general principle is the same, but there is a difference in the practical carrying out of the process according to whether coal or ore is being treated. The difference consists almost solely in the fact that the character of the surfaces of the coal and shaly substances is by nature sufficiently distinct to allow the emulsion to effect their separation without artificial aid, but in the case of ore and its associated impurities the surfaces of the particles are too similar in character, and the mass must be treated with chemicals, generally electrolytes, in order to differentiate the particles and make them susceptible to the action of the emulsion. Apparatus and plans of installations for the treatment of ore and of others for treatment of coal are shown.

Ore Roasting.—H. Fleissner, *Ore Roasting* (Stahl und Eisen, Aug. 13, 1925, vol. 45, pp. 1373-1379). In order to follow the reactions taking place in roasting spathic iron ore it is advisable to study the thermal dissociation of carbonates, the simplest example of which is afforded by the burning of lime. The process is governed by two variables, temperature and pressure. At 900° the carbon dioxide reaches a pressure of about 1 atmosphere; below that temperature the pressure is lower, above it is higher, therefore heating must be carried to at least 900° C. if the carbon dioxide is to escape. In roasting spathic ore the decomposition does not proceed in quite the same way as with limestone, for carbon monoxide is formed in addition to carbon dioxide, and this affects the pressure and the nature of the reactions. Trials were made by the author on the decomposition of iron carbonate ores by heating in a current of carbon dioxide, nitrogen, air, and steam respectively. By heating with an air current at 400° in the presence of steam, oxidation sets in which releases a further supply of heat from the mass to enable the process to continue almost automatically.

A. Weyel, *Investigations of the Desulphurisation of Spathic Iron Ore by Roasting* (Stahl und Eisen, July 23, 1925, vol. 45, pp. 1273-1274). The investigation is concerned with the roasting of the carbonate ores of the Siegerland, and was made with the object of discovering to what extent the desulphurisation depends on the temperature and time of roasting. A diagram shows that at a temperature of 900° maintained for six hours the sulphur is reduced from 2.6 to 0.15 per cent. At 800° C. it is reduced to 0.3 per cent. after $7\frac{1}{2}$ hours. The sulphur still remaining in the ore is in the form of manganous-sulphate, a part of which can be leached out by wetting the ore, and the remainder probably decomposes in the blast-furnace at 900° C.

P. Parrish, *The Combustion of Sulphur-Containing Materials in Hand and Mechanical Burners* (Journal of the Society of Chemical Industry, July 3, 10, 17, 1925, vol. 44, pp. 307-317T, 321-325T, 366-370T). The author describes various types of apparatus in use for burning sulphur-containing materials, such as spent oxide, pyrites, and zinc blende or concentrates. In particular, the practice in the burning of iron pyrites and cupriferous iron pyrites is described. Certain of the Spanish pyrites are explosive; after charging these ores to the burners they detonate and the fine powder formed is a prolific cause of the blockage of the ore bed, thus leading to the formation of scars or clinker. This property of detonation arises from the presence of hydrated silicates in the ore. A preliminary treatment of the pyrites at a suitable part of the burners before charging has in some measure overcome this trouble. The bulk of the lump ore as delivered is usually too large for burning. In lump ore burners crushing is therefore necessary, and the size best suited to lump pyrites burners is $2\frac{1}{2}$ to 3 inches. Many further details concerning the burning of pyrites are given, together with illustrations of the Herreshoff, the Wedge, and the Ridge mechanical burners for pyrites.

Concentration of Ores.—W. Luyken, *Ore Dressing Experiments with the Ores of the Salzgitter Range* (Mitteilungen a.d. Kaiser-Wilhelm Institut für Eisenforschung, 1925, vol. 7, Pt. 3, pp. 25-41). Describes trials with various methods for the concentration of the Salzgitter ores. The composition of ores from different mines is stated, the iron content running from about 25 up to 37 per cent. in the raw ore.

Ore Dressing and Metallurgy (Canada Department of Mines, Mines Branch, 1925, Report 617). This report is in seven parts. Part 5 describes the results of tests on the beneficiation of Canadian iron ores by W. B. Timm. Part 7 describes ore concentration plants in Canada.

W. B. Timm and C. S. Parsons, *The Concentration of Canadian Molybdenite Ores* (Canadian Mining Journal, Sept. 11, 1925, vol. 46, pp. 859-865). The authors give the results of concentration tests on different types of Canadian molybdenite ores.

W. Luyken and E. Bierbrauer, *Arithmetical and Graphic Methods for the Calculation of the Results of Ore Concentration Processes* (Mit-

teilungen a.d. Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 7, Pt. 2, pp. 17-23). The authors give graphic methods for calculating the maximum degree of concentration of ores, which is theoretically attainable and by means of diagrams determine the economic limit to which concentration can be carried.

III.—ORE MINING AND HANDLING.

Ore Mining.—W. R. Crane, *Mine Subsidence in the Red Iron Ore Mines of the Birmingham District, Alabama* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925).

A. B. Sloane, *Swedish Iron Ore Mining* (Iron Age, May 21, 1925, vol. 115, pp. 1, 500-1, 502). Brief particulars are given of the Grängesberg iron ore field.

Ore Handling. *Ropeway at Camargo Iron Ore Mines* (Iron and Coal Trades Review, June 19, 1925, vol. 110, pp. 997-998). The installation described is in operation for the transport of ore from the Camargo mines to the shipping pier on the estuary or inner portion of the Santander Harbour, and has a total length of approximately $3\frac{1}{2}$ miles. It is designed to carry 60 tons per hour.

A. Schruff, *A Modern Ore Handling and Charging Plant* (Stahl und Eisen, Sept. 3, 1925, vol. 25, pp. 1517-1521). A description with plan and illustrations is given of the plant for unloading, transportation, storing and charging of ore, limestone, &c., at the Vulkan Works of the Gelsenkirchener Company, at Duisburg. The unloading wharf is built direct on the Rhine, and the unloading of barges up to 3500 tons is performed by three cranes running on travelling bridges at right angles to the wharf. The ore is hoisted in buckets and deposited either into the large hoppers for feeding the charging buckets underneath, or is piled in the stockyard, whence it can be transported afterwards to the bunkers.

C. Dantin, *New Ore Stockyard at Pont-à-Mousson Blast-Furnaces and Foundries* (Génie Civil, Sept. 12, 1925, vol. 77, pp. 221-224). An illustrated description is given of the new installation at the blast-furnaces of Pont-à-Mousson for storing ore. The equipment consists of ore-breaking machines, hoists and ferro-concrete bunkers, fitted at the bottom with Zublin trap-doors for feeding the ore into the charging buckets.

REFRACTORY MATERIALS.

Magnesite.—K. Niionomy, *The Magnesite Deposits of Manchuria* (Economic Geology, 1925, pp. 25–53). The magnesite deposits of Tashih-chiao contain crystalline magnesite which occurs in stratified form overlying dolomite beds, but without any sharply marked division. The individual magnesite masses are about 2 kilometres long and often several hundred metres thick. Like the Alpine deposits the mineral is often accompanied by talc and graphite.

G. J. Young, *Magnesite Mining at Red Mountain, California* (Engineering and Mining Journal-Press, Aug. 1, 1925, vol. 120, pp. 178–180). Particulars are given of the methods of mining and calcining magnesite at White Diamond Mine in this district.

Dolomite.—L. J. Jones, *Limestone, Dolomite, Lime, and Hydraulic Cement* (New South Wales Geological Survey, 1925, Bulletin No. 9). This report deals with the distribution of limestone and dolomite deposits in New South Wales. Practically all the dolomite raised within the State is used as a refractory lining for the steel furnaces at Newcastle and Lithgow.

Preparation, Properties, and Tests of Refractories.—R. F. Geller and W. L. Pendergast, *The Laboratory Testing of Plastic Refractories* (Journal of American Ceramic Society, July 1925, vol. 8, pp. 441–451). Twelve brands of plastic clay refractories were subjected to standard and laboratory tests for high-grade refractories. They were found equal in quality to the highest grade refractory clay brick. The softening points ranged from cone 30 to cone 34 and the resistance to spalling was uniformly high, from fifteen to fifty quenchings being required to produce failure. Specimens were fired at 1550° C. for forty-eight hours, cooled in the kiln, and quenched at 850° C.

G. M. Darby, *Determination of Grit in Clays* (Chemical and Metallurgical Engineering, Aug. 1925, vol. 32, pp. 688–690). The object of the paper is to list and discuss various methods of determining the size and amount of grit in clays. Experiments were made on two clays from Georgia, two from England, one from Pennsylvania, a talc and a washed talc, and the following quantitative methods of testing were examined :

1. Elutriation (Nobel apparatus).
2. Flotation (E. Sustermeister Method).
3. Flotation (A. D. Little Method).
4. Centrifuging.
5. Wet screening.

The author tabulated his results and forms the following opinions of the methods :

1. Accurate and gives consistent results, but the time required is objectionable.

2. With certain modifications gives good results, and is simple, rapid, and not susceptible to the personal equation of the operator.

3. The personal equation is too large a factor in the manipulation of this method.

4. Unsuitable, because it was necessary to vary the speed of the centrifuge for different clays.

5. Similar to that used by the Bureau of Standards, Washington ; the details are given. Appears to be most suitable when grading finer than 325 mesh is not required.

The author's general conclusion is that for ordinary routine work method 5 is the best method, but if classification of the fines through 325 mesh is required some form of elutriation or flotation must be combined in the test.

M. C. Booze and S. M. Phelps, *A Study of the Factors involved in the Spalling of Fireclay Refractories, with some Notes on the Load and Re-heating Tests and the Effect of Grind on Shrinkage* (Journal of American Ceramic Society, June 1925, vol. 8, pp. 361-382). Of the three factors which affect spalling, elasticity, coefficient of expansion, and rate of temperature change, the first is by far the most important. The coefficient of expansion of fireclay mixtures varies directly with the silica content. Resistance to spalling can be increased by decreasing the coefficient of expansion and by increasing the elasticity, strength, and heat conductivity.

A. J. Dale, *An Investigation of the Effects of Load, Temperature, and Time on the Deformation of Firebrick Material at High Temperatures* (Transactions of the Ceramic Society, 1924-25, vol. 24, pp. 199-215). The author presents results of an investigation of the independent effects of load, temperature, and time on the deformation of typical firebrick material at temperatures within the subsidence range.

A. E. J. Vickers and L. S. Theobald, *Influence of Oxidising and Reducing Atmospheres on Refractory Materials* (Transactions of the Ceramic Society, 1924-25, vol. 24, pp. 98-104). The influence of atmospheres of carbon monoxide and water vapour respectively on the softening range of a cone mixture containing iron oxides has been investigated. For a mixture containing about 2.65 per cent. iron oxide, carbon monoxide has a marked reducing action, and lowers the softening temperature 170° C. With water vapour even more pronounced effects have been obtained.

L. S. Theobald and A. T. Green, *The Temperature Gradients obtained by Different Rates of Heating in Unfired Fireclay Bricks between 15° and 250° C.* (Transactions of the Ceramic Society, 1924-25, vol. 24, pp. 105-123). With the method of investigation employed the exterior and interior temperatures of the unfired brick submitted to various

rates of heating in a specially designed apparatus were determined. The minimum time required for the safe rate of heating three types of unfired fireclay bricks to a temperature of 250° C. has been observed to be 28 hours, 17 hours, and 13.5 hours respectively.

A. T. Green and L. S. Theobald, *An Investigation of the Changes taking Place during the Industrial Burning of Fireclay Bricks* (Transactions of the Ceramic Society, 1924-25, vol. 24, pp. 124-158).

H. M. Thompson, *Getting Double Duty from Firebrick* (Iron Trade Review, May 28, 1925, vol. 76, pp. 1380-1381). A considerable saving in cost is shown by the use of crushed old firebrick bonded with high-temperature cement for making burner blocks and for use as a mortar in an oil-fired heating furnace.

G. H. Reed, *Manufacture of Magnesite* (Paper read before the Ceramic Society, May 1925). The manufacture of magnesite bricks is described. After grinding the magnesite as fine as possible, it is moulded into bricks before calcining, as a more even temperature is obtained in this way than by calcining the broken rock. After placing in the kilns the bricks are slowly heated to 600°, and this temperature is maintained for at least twenty-four hours, after which it is gradually raised to 1650° and maintained there for seventy-two hours. The calcined bricks are then ground with enough water to make a pasty mass, which is then formed into bricks, dried for at least seven days, and then fired in a kiln to 1650°. The burning period is seven days, and six days are allowed for cooling down.

R. Jordan, *The Use and Manufacture of Silica Bricks* (Chaleur et Industrie, Mar. 1925, pp. 135-139). The author indicates some of the uses to which silica bricks are put. Their choice, in preference to other refractories, is in many cases due to their superior mechanical properties. The author explains how the choice of the correct raw material is all-important in the preparation of good silica bricks, but the method of manufacture if faulty can spoil what would otherwise have been a first-class product. Some of the points in manufacture that need watching, and how they are dealt with in the best practice are also described.

W. J. Rees, *Alumina Silica Minerals in Firebricks* (Transactions of the Ceramic Society, 1924-25, vol. 24, pp. 23-26). A number of firebricks of varying composition were examined for the purpose of ascertaining the composition of any alumina silica minerals which had been formed in them during burning.

W. J. Rees, *The True Specific Gravity and After-Expansion of Lime-Bonded Silica Bricks* (Transactions of the Ceramic Society, 1924-25, vol. 24, pp. 66-69). Observations show that for silica bricks with a lime content between 1 and 3 per cent. there is a sufficiently close relation for practical purposes between the true specific gravity and the degree of quartz conversion. For bricks of fine and medium texture there is a close relation between the true specific gravity and the after-expansion. For coarse-textured bricks, containing large fragments of raw material (a quarter inch and above in diameter), there is

no close relationship between the true specific gravity and the after-expansion. This is probably due to the slower rate of inversion of the coarse fragments and their less intimate association with the lime in the matrix of the brick.

J. Horton, *Welsh Brick Industry Thrives* (Iron Trade Review, June 11, 1925, vol. 76, pp. 1520-1521). Brief particulars are given of the methods employed in South Wales for the manufacture of silica brick.

K. Endell, *Refractory Materials for Travelling Grates and Coal-Dust-Fired Boilers: American Practice* (Glückauf, Sept. 19, 1925, vol. 61, pp. 1177-1189). The results of observations made on the firing of American high-pressure boilers are recorded. On account of the high temperatures attained in the combustion chambers, improvements in the quality of firebricks have become necessary, but on economic grounds refractory materials of special quality and composition cannot be used. Any improvement must be in the direction of the use of fireclay of good quality and in methods of manufacture of the bricks. The dry pressing process has been found satisfactory, using quartz-free clays with 40 to 50 per cent. alumina. Water-cooled walls are also being tried.

H. von Wartenburg, *Materials of Construction for very High Temperatures* (Fuels and Furnaces, July 1925; Chemical and Metallurgical Engineering, Aug. 1925, vol. 32, p. 691). A table is given showing the limiting temperatures at which the following can be used: Carbon in form of graphite; zirconia; fused silica; siliceous substances, hard porcelain and Marquardt's mass; metals, platinum, 30 per cent. iridium-platinum, iridium, tungsten, and tantalum. Agents which attack them are included in the table.

Storage of Silica Bricks.—W. J. Rees, *Note on the Storage of Silica Refractories* (Transactions of the Ceramic Society, 1924-25, vol. 24, pp. 62-65). Batches of silica bricks stored in the open were tested as regards any alteration in their physical behaviour. It was found that fine-textured bricks showed no external signs of deterioration, either in mechanical strength or tendency to spall. In bricks of coarse texture, on the other hand, which had been stored for six months, there was slight surface crumbling, and upon carrying out rough spalling tests a much increased tendency to spall was indicated, compared with bricks kept under shelter.

W. J. Rees, *A Further Note on the Storage of Silica Refractories* (Paper read before the Ceramic Society, Sept. 1925). In a previous paper it was shown that silica bricks which had been stored without adequate protection from weather deteriorated very considerably in mechanical strength. In the experiments made to ascertain the mechanism of this loss in strength there were definite indications that bricks made from well-graded batch and well burned would be more resistant to weather than bricks of lower quality. The experiments

were continued to ascertain if this was actually so in the case of commercial silica bricks. From the results of these experiments it is concluded that although high-quality silica bricks were more resistant to deterioration from exposure to weather, some deterioration would take place on prolonged exposure. It was, obviously, desirable to protect the bricks properly during storage, and, especially in the case of blocks, to take precautions to avoid wetting during transit.

FUEL.

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I.—CALORIFIC VALUE.

Calorimetry.—N. S. Osborne, H. F. Stimson, and T. S. Sligh, jun., *A Flow Calorimeter for Specific Heats of Gases* (United States Bureau of Standards, 1925, Scientific Paper No. 503). The calorimeter described was designed for measuring the specific heats of gases accurately at pressures below 100 atmospheres and temperatures below 150° C. It is of the flow type, with provision for adding heat electrically and for measuring the temperature rise by means of platinum-resistance thermometers.

Combustion of Fuel.—T. Sunnen, *The Control of Combustion by Means of Triangular Diagrams* (Chaleur et Industrie, June 1925, pp. 266–269). The author expresses the composition of flue gases in the form of a triangular graph, and from this he can deduce in a simple manner whether the proportion of air in the combustible mixture entering the furnace is correct, or, if not, by how much it should be altered.

R. J. Sarjant, *Furnace Heating* (Fuel, May, June, July, Aug., Sept. 1925, vol. 4, pp. 199–208, 232–244, 276–285, 328–336, 383–395). The author continues his series of articles on furnace heating, the subject being dealt with under the following heads: The flow of gases in furnaces, the draughting of metallurgical furnaces, fuel economy, utilisation of waste heat, waste heat boilers, boiler testing, heat insulation, recuperation, development of reheating furnaces, the new form of Siemens furnace, coal-fired furnaces and gas-fired furnaces, fuel consumption in reheating furnaces, the question of coal-firing *versus* gas-firing in gas furnaces, soaking pits, low-temperature heat treatment furnaces, sheet annealing furnaces, furnace atmospheres, heat-resisting steels, open-hearth furnaces and their construction.

R. J. Sarjant, *Furnace Heating* (Fuel Economy Review, June 1925, vol. 4, pp. 13–20). The author discusses the more fundamental factors

in the production of heat. The subject is dealt with under the following headings: Selection of fuel, selection of the furnace, production of flame, radiation, length and character of flame, combustion of solid fuel, fuel-bed conditions, control of combustion, and unburnt combustible. A series of heat losses in some types of furnaces is given.

B. Moore and F. S. Sinnatt, *Ignition of Solid Fuels* (Fuel, May 1925, vol. 4, pp. 194-198). For comparison of the ignition temperature of different coals small samples were subjected to oxidation in a stream of oxygen heated to the glow temperature for that particular coal, and the rate of temperature rise was measured. Each coal was found to have a critical temperature below which it did not react with oxygen and above which its avidity for oxygen was so great as to cause it to glow. The initial rate of temperature rise prior to glowing was regarded as characteristic of the liability of the coal to spontaneous combustion. One aspect of the tendency of solid fuels to ignite spontaneously was studied and a new characteristic, the ignition factor, has been suggested.

H. Lent, *Heat Transmission of Gases* (Stahl und Eisen, June 11, 1925, vol. 45, pp. 938-940). The author presents a general survey of the laws of heat transmission of gases by conduction, convection, and radiation. In particular, it is shown that gases such as carbon dioxide, steam, hydrocarbons, and possibly carbon monoxide, emit heat rays and that the radiation capacity of these gases at temperatures above 500° C. is very great. This factor is of considerable influence upon the heat transmission conditions in boilers and furnaces.

Industrial Heating.—H. F. Smith, *Industrial Heating* (Transactions of the American Society for Steel Treating, Sept. 1925, vol. 8, pp. 350-356). The author discusses industrial heating from the viewpoint of the engineer.

E. C. Evans, *Solid Smokeless Fuels; Their Properties and Uses* (Journal of Society of Chemical Industry, July 31, 1925, vol. 44, pp. 383-391T). Smokeless fuels are classified into (1) natural smokeless fuels, such as anthracite and dry steam coal; (2) coke made at high temperatures, namely, gas coke, blast-furnace coke, and specially reactive high-temperature cokes; (3) low-temperature cokes. The characteristics, properties, and forms in which these fuels as used are discussed.

A. Simonini, *Economy in the Consumption of Solid Fuel* (Metallurgia Italiana, May, June 1925, vol. 17, pp. 201-225, 260-280). A full review is presented of the recent progress in the adoption of methods for economising solid fuel.

Pulverised Coal.—L. V. Andrews, *A Microscopic Study of Pulverised Fuel* (Mechanical Engineering, May 1925, vol. 47, Section II., pp. 429-432). The usual way of expressing the fineness of pulverised fuel by giving the percentages of it which will pass through 100- and 200-mesh screens is not sufficient because no indication is given of the state of

comminution of the portion which passes the 200-mesh screen. The finer the state of division of the 200-mesh powder the more readily and completely will it burn. The author has made a number of photomicrographic prints in an endeavour to show what kind of product is yielded by different types of mill. His conclusion is that the standard 100- and 200-mesh method of testing pulverised fuel is at fault, in that it does not show the amount of pulverisation done; he suggests that the microscope should be used or more elaborate sieve analyses made when it is desired to know exactly the quality of the fuel delivered by the mill.

D. Brownlie, *Pulverised Fuel; Latest Developments Considered, along with Low-Temperature Carbonisation in Relation to the Mining Industries* (Transactions of the Institution of Mining Engineers, 1925, vol. 69, pp. 245-279). The paper gives a brief description of the most recent developments of pulverised fuel firing as applied to the generation of steam, and the bearing of this matter on the subject of low-temperature carbonisation.

W. R. Chapman, *Pulverised Fuel for Boilers and Furnaces* (Fuel, Aug., Sept. 1925, vol. 4, pp. 340-343, 396-400). General practice in the use of pulverised fuel is described, including the consideration of such questions as coal-drying, pulverisation, transport of powdered fuel, the combustion chamber and its lining, the disposal of ash, and the fuels suitable for use.

M. Sohm, *Boiler Heating with Pulverised Coal* (Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Mar. 1925, pp. 234-246). A description is given of the boiler plant at the central generating station of the mines of Bruay. Since January 1922 sixteen boilers in one boiler-house have been fired with pulverised coal, and ten Stirling boilers in the second boiler-house are being equipped with similar furnaces. Tests and working results are described.

F. Ebel, *Trials with Coal-Dust Firing* (Glückauf, June 20, 27, 1925, vol. 61, pp. 757-768, 789-793). An account of a lengthy series of trials in the firing of boilers with coal-dust at a German colliery. The effects of fluctuation of the boiler load, of the fineness of grinding, and of the dividing of the air into primary air and secondary air were studied.

H. Kreisinger, J. Blizard, C. E. Augustine, and B. J. Cross, *Tests of a Large Boiler Fired with Powdered Coal at the Lakeside Station, Milwaukee* (United States Bureau of Mines, 1925, Bulletin 237). This report gives the result of twenty-six tests of an Edgemoor boiler fired with powdered coal. The object of the tests was to determine the thermal efficiencies and capacities obtainable by burning powdered coal under large boilers, and the possibility of operating such boilers continuously at high efficiency without destructive effect on the furnaces and without difficulties in ash removal.

F. Wintermeyer, *Prospects and Development of the Use of Pulverised Coal* (Feuerungstechnik, Dec. 1, 1924, vol. 13, pp. 47-50). The

author studies the various types of furnaces and their individual characteristics, the construction of the burners, and of the combustion chambers. The chief advantages of heating by pulverised fuel are summarised : (1) High efficiency, owing to losses caused by excess of air, incomplete combustion, and running empty being small ; (2) ease of regulation ; (3) rapidity of starting up ; (4) ability to use inferior coals ; (5) ability to extinguish the fire immediately in case of accident. The author adds, however, a word of warning of the danger of explosion when pulverised fuel is not treated with due care.

H. W. Brooks, *Burning Pulverised Coke Breeze* (Iron Age, July 16, 1925, vol. 116, pp. 165-166). A brief discussion of the difficulties encountered in the firing of pulverised coke breeze.

W. J. Wohlenberg and D. G. Morrow, *Radiation in the Pulverised Fuel Furnace* (Mechanical Engineering, Aug. 1925, vol. 47, pp. 627-632). The article deals with the first principles of radiation as applied to burning pulverised fuel. The radiating power through the flame surface is controlled by the size of the particle, and is relatively low when compared to black-body radiation. The heat absorption intensity of a furnace surface depends on the amount and disposition of the refractory lining. It is possible to indicate, by comparisons, what furnace proportions will give best results.

Grinding and Pulverising Machines with Air Separation (Chaleur et Industrie, May 1925, pp. 246-248). A description of a few of these machines that are in more general use.

R. H. Parsons, *The Power Required for Pulverising Coal* (Electrical Review, May 1, 1925, vol. 96, pp. 684-685). The author sets out to show that the advantages accruing from the use of pulverised fuel are largely if not entirely set-off by the extra capital expenditure on the plant and the power needed to pulverise the fuel. He takes all his data from a paper presented recently to the American Society of Mechanical Engineers by H. Kreisinger.

H. E. Newall and R. Palm, *Hazards of Pulverised Fuel Systems* (Mechanical Engineering, Nov. 1924, vol. 46, pp. 783-784; Engineering, Jan. 2, 1925, vol. 119, pp. 25-26). The precautions against fire risks to be observed in planning installations for the use of pulverised fuel are noted. Where practicable the pulverising of the coal should be performed in a detached building used for no other purpose. Driers, unless in the boiler-room, should be similarly segregated. Buildings containing pulverising equipment should be constructed of fireproof materials and fitted with explosion doors and good ventilating arrangements.

Use of Coke for Boiler Firing.—*Coke Breeze Utilisation* (Electrician, Sept. 25, 1925, vol. 95, p. 362). A very brief account is given of the beneficial results obtained by mixing coke with coals and burning the mixture under a boiler. Tests on a "Cochran" vertical boiler with a "turbine" forced draught steam jet furnace were made with the conditions kept as uniform as possible ; using feed-water almost

boiling, a good washed coal evaporated 10·2 lbs. of water per lb., whereas coke breeze alone only evaporated 7·3 lbs. of water per lb. A mixture of 3 parts coke breeze and 2 parts coal evaporated 10·7 lbs. of water per lb. of mixed fuel, or 2·2 lbs. of water more than would be expected by simple calculation.

II.—COAL.

Africa.—*Mineral Resources of Somaliland* (First Report on the Geology and Mineral Resources of British Somaliland, London, 1924, pp. 53). A review is given of the mineral resources of British Somaliland. Occurrences of coal, lignite, petroleum, oil shale, manganese ore, molybdenite, and graphite are described. Of the minerals found, coal is by far the most likely to be of economic value in the immediate future.

Australia.—*The Coal Measures of Queensland* (Colliery Guardian, Sept. 18, 1925, vol. 130, p. 680). Brief particulars are given of the Bowen River coal-field.

Belgium.—G. C. Van Esbroeck and M. Touwaide, *Some Reports of the Exploitation of Coal in Campine* (Revue Universelle des Mines, July 1, 1925, vol. 7, pp. 6-24).

Canada.—M. J. Patton, *The Coal Resources of Canada* (Iron and Steel of Canada, Aug. 1925, vol. 8, pp. 162-169). A study of the fuel situation in Canada.

China.—C. C. Liu and J. C. Chao, *Preliminary Report on the Geology and Mineral Resources of Kiangsu* (Geological Survey of China, Pekin, 1924). A brief description is given of the geology of the district, and of the different coal-fields.

H. C. Tan, *Geology of the Ho-Kang Coal Field, Heilungkiang* (Bulletin of the Geological Survey of China, Dec. 1924, No. 6, pp. 1-12).

L. F. Yih and C. Li, *Geology of the Coal Fields of Chin Hsien and Hsuan Cheng, Anhui* (Bulletin of the Geological Survey of China, Dec. 1924, No. 6, pp. 13-20).

C. C. Wang, *The Coal Fields of the South-West Part of Huai Yüan Hsien, Anhui* (Bulletin of the Geological Survey of China, Dec. 1924, No. 6, pp. 21-26).

J. G. Andersson, *Report on the Chang Chiu Coal Field in Shantung* (Bulletin of the Geological Survey of China, Dec. 1924, No. 6, pp. 51-61).

F. F. Mathieu, *Geological Age of the Coal Basin of Pen Hsi Hu* (Bulletin of the Geological Survey of China, Dec. 1924, No. 6, pp. 63-66).

Y. T. Chao and C. C. Tien, *On the Stratigraphy of the Tse Chow and Liu Ho Kou Coal Fields, on the Border between S. Chihli and*

N. Honan (Bulletin of the Geological Survey of China, Dec. 1924, No. 6, pp. 67-85).

England and Wales.—T. H. Rowlands, *The Correlation of the Coal Measures in the Western Portion of the South Wales Coalfield. Part III. —The Upper Part of the Pennant Series of the Swansea District* (Proceedings of the South Wales Institute of Engineers, 1925, vol. 41, pp. 257-298).

France.—Georges, *Statistics of the Mines of the Pas-de-Calais in 1924* (Revue de l'Industrie Minérale, Mémoires, Aug. 1, 1925, pp. 343-348). A brief comparison of the general conditions in the Pas-de-Calais basin in 1924 with those of 1913. At the end of 1924 the pre-war situation was re-established.

New Zealand.—W. P. Evans, *Brown Coals of New Zealand. Organic Sulphur as a Factor in Determining the Rank of a Lignitic Coal* (Journal of the Society of Chemical Industry, May 22, 1925, vol. 44, p. 258T). In determining the rank of a coal by the percentages of carbon and hydrogen in the coal substance, it is usual to eliminate sulphur as being a part of the inorganic matter accompanying the coal. In the case of bituminous coals this plan may be sufficiently accurate, but coals of lower grade often contain fairly large amounts of organic sulphur, and in determining the relative rank of such coals the elimination of sulphur from the coal substance cannot be justified. New Zealand brown coals are shown ranked according to both systems, and the inclusion of organic sulphur considerably alters the position of some of the coals in the rank.

W. O. R. Gilling and W. P. Evans, *New Zealand Brown Coals, with Special Reference to their Use in Gas-Producers and for Low-Temperature Distillation* (Journal of the Society of Chemical Industry, May 29, 1925, vol. 44, pp. 259-263T).

J. A. Gilman and W. P. Evans, *New Zealand Brown Coals. Low and Medium Temperature Carbonisation Experiments with Typical High Sulphur and Low Sulphur Coals* (Journal of the Society of Chemical Industry, May 29, 1925, vol. 44, pp. 263-264T).

W. P. Evans, *New Zealand Brown Coals. Elimination of Sulphur during Carbonisation* (Journal of the Society of Chemical Industry, May 29, 1925, vol. 44, p. 265T).

W. P. Evans, *New Zealand Brown Coals. Some Hard Jet-Like Inclusions Found in the Resin-Bearing Seams at Coal Creek Flat, Central Otago* (Journal of the Society of Chemical Industry, May 29, 1925, vol. 44, p. 266T).

L. R. Dunn, *New Zealand Brown Coals. Some Leaching Experiments with Avoca, Mossbank, and Coal Creek Flat Coals* (Journal of the Society of Chemical Industry, June 5, 1925, vol. 44, p. 275T).

H. O. Askew, *The Inorganic Constituents of Some New Zealand Coals* (Journal of the Society of Chemical Industry, June 5, 1925, vol. 44, p. 276T).

United States. C. P. Ross, *Geology and Ore Deposits of the Aravaipa and Stanley Mining Districts, Graham County, Arizona* (United States Geological Survey, 1925, Bulletin 763). This report includes a description of the general features of the coal-fields of this region.

E. T. Hancock, *Geology and Coal Resources of the Axial and Monument Butte Quadrangles, Moffat County, Colorado* (United States Geological Survey, 1925, Bulletin 757). The report contains information on the stratigraphy, structure, and distribution of the coal-beds of this district, together with particulars of the characteristics of the coal and numerous analyses of samples from the Axial and Monument Butte quadrangles and neighbouring coal-fields.

Analyses of Utah Coals (United States Bureau of Mines, 1925, Technical Paper 345). This report contains numerous analyses of mine samples of Utah coals. In addition a brief description is given of the geological structure of the coal-fields, a summary of the mining methods used, the uses and markets for the coal, and a statement of the production by counties.

Constitution and Chemistry of Coal. W. A. Bone, *The Constitution of Coal* (Journal of the Society of Chemical Industry, June 19, 1925, vol. 44, pp. 291-298T). In the study of the constitution of coal three methods have been principally employed—namely, the thermal decomposition of the coal substance; its fractionation by some selected sequence or concentration of solvents; its oxidation, hydrogenation, and halogenation. The decomposition of coal substance commences at about 350° C., and with all coals there is a well-defined critical temperature between 700° and 800°, which corresponds with a rapid increase in the quantity of hydrogen evolved. The evolution of methane and other hydrocarbons almost entirely ceases at about 700°. By the action of solvents the coal substance is divisible into three fractions: (1) insoluble in pyridene; (2) soluble in pyridene, but insoluble in chloroform; and (3) soluble in both pyridene and chloroform. The author prefers the use of benzene as a coal solvent in a special form of extract, and gives results of experiments, by which four fractions were obtained, the nature and composition of which is stated. The coking propensities of a coal appear to depend upon the development in it of a special type of component which yields a fraction consisting of amorphous cinnamon-brown substances containing small amounts of both nitrogen and sulphur, which form colloidal solutions with the benzene. These substances appear to be of a humic type. It may be provisionally concluded that coals yielding less than about 2 per cent. of this fraction are non-coking, whilst those yielding about 2.5 per cent. will probably show incipient coking properties. The

coking propensities increase with the yield of the fraction until with strongly coking bituminous coals it will usually amount to between 4 and 7 per cent. Incidentally, the author puts in a plea for the retention of the terms bright coal, dull coal, and mineral charcoal to indicate those constituents to which the names vitrain, clairain, durain, and fusain have lately been applied.

J. Lomax, *The Microstructure of a Coal-Seam* (Fuel Research Board, 1925, Technical Paper No. 11). The report deals with photomicrographs of the Lanterne seam, which belongs to the subdivision of the South Wales coal-measures. The photomicrographs show megaspores and microspores by transmitted light in natural colours. As seen under the microscope, thin sections of coal appear in colour ranging from light yellow to deep amber and red, dependent in part upon the degree of thinness of the specimen and in part on the nature of the coal substance.

R. Lessing, *The Inorganic Constituents of Coal* (Journal of the Society of Chemical Industry, June 12, 1925, vol. 44, pp. 277-283T). The mineral constituents of coal are enumerated and classified according to their origin, and the approximate distribution and characteristics of mineral matter in bituminous coal are indicated as ascertained from the results of the investigation.

R. Thiessen, *Origin of the Boghead Coals* (United States Geological Survey, 1925, Professional Paper 132-I). When examined under the microscope in thin sections boghead coals are found to differ from all other bituminous shales in that they contain or are composed largely of peculiar irregular oval yellow bodies. According to origin, bituminous shales and cannel coals may be classified into humic, spore, ceric, resinous, and algal deposits. The yellow bodies of the boghead coals are not derived from spores, but represent colonies of alga-like organisms heretofore not well known. In all the bogheads investigated these colonies, described as *Reinschia* and *Pila*, are similar to an organism now living in the salt lakes and lagoons of South Australia. The living organism has been termed *Elæophyton*, because of the large amount of oil it contains. The paper is accompanied by a number of photomicrographs.

B. Moore, *Absorption of Moisture by Coal and Other Fuels* (Journal of the Society of Chemical Industry, May 1, 1925, vol. 44, pp. 200-205T). Experiments made with various types of fuel ground to specific degrees of fineness indicate that a linear relation exists between the moisture contained in fuels and the degree of humidity in the air.

Utilisation of Peat.—R. Mollwo Perkin, *Recent Progress in the Peat Problem* (Paper read before the British Association, Aug. 27, 1925: Iron and Coal Trades Review, Sept. 4, 1925, vol. 111, p. 357). The commercial utilisation of peat is discussed and reference is made to a new system. The many methods suggested for getting rid of the

bulk of the water from peat can be roughly classified as follows: (1) Macerating, (2) heating and compressing, (3) electrical, (4) chemical, (5) macerating, heating under pressure, and briquetting. The author has found that a combination of maceration under suitable conditions extruding as much water as possible, passing it into an autoclave and heating under regulated pressure, and then suddenly discharging by means of a sluice valve and afterwards filtering or pressing off the water, with a final passing of the peat so treated into a press, gave briquettes containing from 18 to 20 per cent. of water. When these briquettes were carbonised under suitable conditions, the charcoal so obtained compared favourably with the wood charcoal now employed in the iron industry. The results of tests showed that peat containing more than 20 per cent. moisture could not be satisfactorily carbonised at low temperatures.

K. Homolka, *Method of Drying Peat* (Chemiker Zeitung, 1925, vol. 49, pp. 429-430). The freshly cut peat is pulped and fed into a suction filter, and the mass is then covered with petroleum. Vacuum is then applied below, and the water is sucked through the peat followed by the petroleum, leaving a product containing 25 to 28 per cent. of water and 0.5 per cent. of petroleum. The petroleum drawn through the mass is used repeatedly and then distilled to recover certain wax-like constituents dissolved from the peat.

A. Hausding, *A New Pressed Peat Factory* (Zeitschrift des Vereines Deutscher Ingenieure, June 6, 1925, vol. 69, pp. 784-787). A factory for the manufacture of pressed peat blocks has just been put in operation on a peat moor near Friedland. The peat is dug by electrically driven dredgers. The raw peat contains 88 to 90 per cent. water, and this is reduced by drying in the open to 45 to 55 per cent. It is then taken to the factory, shredded and dried in a tubular drier down to 12 per cent. water, the heat being supplied by waste steam from the engine for driving the machinery, presses, hoists, &c. The output is 120 tons of pressed peat blocks per day.

Peat Resources of Poland (Journal of the Royal Society of Arts, Sept. 4, 1925, vol. 73, p. 941). A brief summary of the quality, quantity, and distribution of the peat resources of Poland.

III.—COKE.

Manufacture of Coke.—R. A. Mott, *By-Product Coke-Oven Practice* (Fuel, May, June, July, Aug., Sept. 1925, vol. 4, pp. 185-193, 245-251, 310-321, 344-352, 373-381). The author continues his survey of progress in by-product coke-oven practice. The fifth article of the series describes and illustrates the Semet-Solvay oven; the sixth article deals in the same way with the Coppée oven, showing illustrations of the Coppée waste-heat oven: the Simplex, Huessener, Collin, Wilputte, 1925—ii.

the Koppers taper, and the Becker ovens are next described; the eighth article deals with the Otto, Simon-Carvès, and the Piette ovens; and in the ninth article the waste-heat, recuperative, and regenerative types are compared, and the effect of the width of the oven on the quality and output of the coke produced is discussed.

T. Biddulph Smith, *Flow of Gases in the Coke-Oven* (Gas World, 1925, vol. 82, Coking Section, pp. 38-41). In order to study the internal conditions of a charge during coking, a number of sampling pipes were inserted at different heights in the charge. It was found that unfissured coke offers a resistance to the passage of gases 14.6 times greater than that of the column of coal, consequently gases mainly pass during coking through the coal. Analyses of the gas at the sampling points show that the hydrocarbons evolved consist mainly of paraffinoid substances, which become cracked to hydrocarbons, hydrogen, and methane, and deposit carbon during their passage through the hot horizontal crust of coke sponge at the top of the charge.

W. Forster, *Flow of Gases in the Coke-Oven* (Gas World, 1925, vol. 82, Coking Section, pp. 48-52). The nature of the composition and the amount of the volatile by-products appear to offer evidence that the gases pass through the hot coke rather than through the cooler cores of coal. The extent to which the unsaturated hydrocarbons decompose by the action of heat indicates that this decomposition takes place not in the crown of the oven above the top level of the side heating flues, but rather in the hot coke. The fact that coking coals can be more quickly carbonised when mixed with coke or non-coking coals appears to show that the hot products of carbonisation are then able to circulate through the coal core and so hasten carbonisation by convection, whereas with coking coals alone the plastic layer between the coke and the coal from which it is formed presents a barrier.

G. E. Foxwell, *Flow of Gases in the Coke-Oven* (Gas World, 1925, vol. 82, Coking Section, pp. 56-58). In reply to Smith's views concerning the passage of gases through the coal mass in the coke-oven, the author points out that the size and orientation of the coke pores are no criterion as to the passage or otherwise of gas from other parts of the charge. The examination of the distribution of sulphur dioxide in the gas products is misleading, especially since the sulphur dioxide if introduced into the charge would alter the heat distribution, so as to upset the normal traverse of gas through the charge.

A. Thau, *Path of Travel of Gases in the Coke-Oven* (Gas World, 1925, vol. 82, Coking Section, pp. 59-60). It is suggested that greater resistance to the passage of gas would be offered by the fine-grained coke produced in the neighbourhood of the oven wall than by the semi-carbonised and raw coal in the centre. The author supports the theory of the inward and upward flow.

G. E. Foxwell, *Flow of Gases in the Coke-Oven* (Gas World, 1925, vol. 83, Coking Section, pp. 76-77). Previous trials point to the conclusion that the viscosity of the gases does not vary greatly, and

evidence of this is afforded by the fact that the gases are mixtures of gases from various parts of the charge at different temperatures, and consequently they do not show such wide variations in hydrogen as those gases produced by high and low temperature carbonisation. The resistance due to the formation of an upper plastic layer is not permanent, but falls after a time to less than that due to the coal column. The effect of the lateral pressure exerted by the plastic layer is thought to be responsible for the increased porosity at the centre of the coke charge.

A. Thau, *Formation of Coke* (Fuel, Apr. 1925, vol. 4, pp. 169-175). To study the question of the progress of coke formation in ovens, samples of coal were placed in a perforated iron box and embedded in the charge of a coke-oven, so that they could be withdrawn as desired and quenched in sand. It would appear that coking layers do not run parallel to the oven walls, their direction being dependent upon the changes of temperature in the walls and the penetration of heat through the charge. Irregular heat penetration causes tension cracks in the coke, weakening it so that disintegration takes place more readily on discharging. With unscreened coal the direction of the coking layers is very irregular, and the coke becomes unsuitable for metallurgical purposes. The formation of spongy coke near the top of an oven is found to be due to the carbonisation of the top of the charge by radiant heat from the crown arch, and the resistance to the exit of tarry vapours through this hot zone is diminished. Consequently the tar accumulated in the uncarbonised centre portions of the charge decomposes in its attempt to leave by this path of least resistance.

H. J. Hailstone, *Short Bibliography of Coke* (Gas Journal, May 27, 1925, vol. 170, pp. 591-592). The article contains a fairly complete bibliography of the subject and some indications as to where to seek for further information.

Testing of Coke.—G. E. Foxwell and R. V. Wheeler, *The Testing of Coke* (Fuel, Aug., Sept. 1925, vol. 4, pp. 353-356, 410-413). Consideration is given to methods of sampling coke, determination of the real and apparent specific gravity, determination of porosity, shatter test, tumbler test, and crushing strength. The methods of testing the fusibility and reactivity of coke are also described—namely, the carbon dioxide method, the oxygen method, the air method, and the temperature of ignition method.

Structure of Coke.—H. J. Rose, *The Study of Coke Macrostructure* (Industrial and Engineering Chemistry, Sept. 1925, vol. 17, pp. 895-901). The preparation of samples of coke for micro- or macro-examination is not easy. At one time it was difficult if not impossible to get sufficiently large plane surfaces cut in the specimen, but this is overcome now by using a thin alundum cutting wheel at high speed. When a coke specimen is examined it is seen that the cells have a glossy surface

which reflects light strongly; the resultant field is a black background broken by hundreds of points of dazzling light, which is trying to the eyes and causes halation on photographic plates. The author has overcome this difficulty in three ways: (1) by grinding and polishing the coke surface, (2) by filling the cells with a white composition, and (3) by taking inkprints from the coke surface. He describes all three methods in detail.

Combustibility of Coke. F. Häusser, *Combustibility and Strength of Metallurgical Coke Graded in Various Sizes* (Stahl und Eisen, June 4, 1925, vol. 45, pp. 878-885; Glückauf, June 6, 1925, vol. 6, pp. 693-700). The author reports the results of experiments made to determine the influence of the coking conditions, such as temperature and time and the width of oven, on the combustibility of the coke. The length of coking time and overheating affect very little the burning qualities of the coke, nor are they much influenced by narrowing the ovens. The qualities upon which combustibility appears chiefly to depend are the character of the coking coal and the size of the coke. Coke of 30 to 50 millimetres size, for example, showed a much higher degree of combustibility than a similar coke of 70 to 90 millimetres size. The addition of iron-bearing substances to the coal, such as rolling-mill scale or pyrite residues, appears to increase the combustibility, but also increases the liability to break on falling. The strength of coke is also reduced in the same way by coking in narrow ovens. The strongest coke is produced from the most finely ground coal, and in furnace practice the strength of coke is considered to be of more importance than combustibility.

F. Häusser and R. Bestehorn, *Combustibility and Strength of Metallurgical Coke* (Berichte der Gesellschaft für Kohlentechnik, 1925, pp. 345-386).

C. Holthaus, *Influence of Overheating on the Reactivity of Coke* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1131-1133). The author points out that different investigators are not in agreement as to the effect of overheating of the charge on the reactivity of the coke. Some maintain that overheating has little influence; others that it seriously reduces the reactivity. A distinction should be drawn between the "after-heating" of a charge that is not completely coked, and the "over-heating" of a charge that is completely coked. Experiments on a small scale were made with charges of 50 grammes of semi-coke, which were heated in an electric furnace, the temperature being raised from 600°, at the rate of 30° in every ten minutes, till 1200° C. was reached. The charge was then completely coked and was held at 1200° for five, ten, and twenty hours. The period of heating from 600° to 1200° was the one during which the coke increased in specific gravity and lost in reactivity. The subsequent overheating or baking after complete coking had no further effect on the combustibility.

Low-Temperature Carbonisation.—N. Simpkin, *Some Aspects of Low-Temperature Carbonisation* (Fuel, May 1925, vol. 4, pp. 218–221). Difficulties of low-temperature carbonisation chiefly lie in the great differences of the kinds of coal from which low-temperature coke is prepared. To overcome this difficulty different types of retorts have been constructed which may be briefly enumerated as follows: (1) Retorts on the principle of a tunnel kiln, the coal passing through a heated zone in suitable containers. (2) Retorts in which the coal moves by means of its own weight, the retort being vertical and fed from the top, and the product withdrawn at the bottom. (3) Retorts in which agitation of the coal is produced by the rotation of the retort in the form of an inclined cylinder. (4) Retorts in which the coal is forced through mechanically by means of rotating arms. Certain processes are used with the primary object of obtaining not a smokeless fuel, but the tar and ammonia, followed by the complete gasification of the carbonised residue. In such instances the retort is usually of the internally heated type, with a continuous feed.

J. D. Davis, P. B. Place, and P. Edeburn, *Heat of Carbonisation of Coal* (Fuel, July 1925, vol. 4, pp. 286–299; Report of United States Bureau of Mines). Determinations were made of the heat of carbonisation of American coals at temperatures up to 650° C. in an atmosphere of nitrogen, using an adiabatic twin calorimeter. All the coals were slightly endothermic below 300°. At the point of primary decomposition, 325° to 375°, there was a rapid evolution of heat, reaching a maximum at 400° to 475°, then decreasing to about 600°, after which some coals showed an increase. The maximum heat of reaction did not exceed 50 calories per gramme. The primary products of distillation gave endothermic reaction heats.

F. Schütz and W. Buschmann, *Low-Temperature Carbonisation of Coal* (Stahl und Eisen, July 16, 1925, vol. 45, pp. 1232–1242). A general account is given of practice in the low-temperature carbonisation of coal, the production and uses of semi-coke, the recovery of primary tar and the various distillates and oils obtainable therefrom, the recovery of petrol and the utilisation of the residual gases, chiefly methane and hydrogen. A list of ninety-four compounds obtainable from the tar and gases is given, with their chemical symbols and boiling points. Tables showing the composition of the gases of distillation and of benzene derived from primary tar are also given.

F. Schütz and W. Buschmann, *Fellner-Ziegler Process of Low-Temperature Carbonisation* (Iron and Coal Trades Review, July 24, 31, Aug. 7, 1925, vol. 111, pp. 140, 182–183, 212–213). A description is given of the Fellner-Ziegler or "Allkog" process, and its economic possibilities and prospects are discussed. The process has been in operation in Germany during the past three years, and consists in the low-temperature carbonisation of bituminous materials in continuous retorts. The results obtained with a number of different kinds of coal are given.

Low-Temperature Carbonisation (Electrician, Aug. 21, 1925, vol. 95, p. 211). By a new procedure invented by E. R. Sutcliffe, called the "Pure Coal Briquette" process, roughly pulverised coal is mixed with 10 to 15 per cent. of coke breeze or similar material so as to give a blend which does not expand on carbonisation. The mixture is then briquetted without any binder in a special press at a pressure of 6 to 10 tons per square inch. Carbonisation is carried out in special retorts, the briquettes passing in at the top and out at the bottom, being converted into intensely hard smokeless fuel which can be lighted with paper and matches like coals, but giving a very hot fire on account of the high emission of radiant heat. The average temperature of carbonisation is 1400° to 1600° F., which may, however, be varied so that a large yield of oils with little pitch can be obtained and the volatiles converted into valuable products. The average yield from 1 ton of 25 to 35 per cent. volatile coal is about 11,000 cubic feet of town's gas of 500 B.Th.U., 25 gallons of oils, over 40 lbs. of ammonium sulphate, and the equivalent of 70 per cent. of the weight of the coal as free-burning smokeless fuel. The briquettes are claimed to be harder than metallurgical coke.

A. Thau, *A New Low-Temperature Carbonisation Process for Coal* (Fuel, June 1925, vol. 4, pp. 259-263). The paper is a translation of the article which appeared in Stahl und Eisen and Glückauf (Journal of the Iron and Steel Institute, 1925, No. I. pp. 454). The Dobbelsstein retort and process are described.

F. Müller, *Low-Temperature Coking in Inclined Double Rotary Furnaces* (Stahl und Eisen, June 4, 1925, vol. 45, pp. 885-887). The apparatus consists of a wrought-iron cylinder 10 feet diameter with a smaller one, 5½ feet diameter, revolving concentrically within the larger one. The inner cylinder is fitted with a spiral of sheet iron, and the coking coal is fed in at the lower end of the cylinder, and is conveyed by the rotating spiral to the upper end. During its passage the coal is preheated and dried by contact with the hot walls of the small cylinder. At the upper end the coal is discharged into the large cylinder and travels back by gravity as the cylinder rotates within a brick combustion chamber, which is fired in such a manner as to prevent overheating of the cylinders. The gases of distillation pass off at the upper end of the large cylinder. The process is improved by admitting superheated steam during carbonisation.

G. Cantieny, *Rotary Furnace for the Low-Temperature Carbonisation of Coal* (Zeitschrift des Vereines Deutscher Ingenieure, Apr. 25, July 11, 1925, vol. 69, pp. 547-553, 929-932; Glückauf, Aug. 8, 1925, vol. 61, pp. 1000-1002). A rotary furnace was installed at a colliery at Karnap in Westphalia to deal with the coal dust resulting from the process for drying coal after washing. An illustrated description of the plant and of the carbonising process is given, with particulars of the by-products recovered.

The "L and N" Process of Low-Temperature Distillation (Iron and

Coal Trades Review, Oct. 16, 1925, vol. 111, pp. 591-593). The plant and operation of the "L and N" process are described and illustrated. Carbonisation is effected by internal heating of a horizontal revolving retort by an inert gas.

The Works of the Midland Coal Products, Ltd. (Iron and Coal Trades Review, July 31, 1925, vol. 111, pp. 175-177). An illustrated description is given of these works situated at Nottingham, where a plant is in operation for carbonising colliery fines. The material is first passed through a Rheolaveur washery before briquetting in ovoid shape. The retorts are designed on lines similar to a blast-furnace. The bottom section is in the form of an inverted cone, with the water-cooled discharging door at the apex. Each retort is provided with twelve tuyeres for supplying air and steam to the charge. Each pair of retorts has a common gas main leading to a Lymn washer. The capacity of each retort is approximately 5 tons. There is a scrubbing plant and the usual settling tanks for dealing with the tar and liquor. Carbonisation is effected by a small part of the descending charge being burnt to carbon monoxide. This hot gas ascending distils the volatile matter in the descending charge at a low temperature, the crude gas leaving the retorts at a temperature of 200°C . The carbonised briquettes are cooled below the blast inlet by a small quantity of steam which ascends and becomes decomposed on reaching the hot zone. The normal through-put of each retort is 1 ton of briquettes per hour. The amount of steam required is about 200 lbs. at 20-lbs. pressure per ton of fuel treated; in addition there is required about 25,000 cubic feet of air at 6-inch w.g. per ton of fuel. The analysis of the carbonised briquettes is: Ultimate analysis (dry basis): Carbon, 86.19; hydrogen, 0.58; sulphur, 0.91; nitrogen, 0.82; oxygen (difference), 0.03; ash, 11.47 per cent. Calorific value: B.Th.U. 12,500. The gas produced has the following average analysis: CO_2 , 1.4; CO, 28.7; H_2 , 15.0; CH_4 , 5.1; N_2 , 50.2 per cent.

The Carbonisation of Pulverised Fuel at Low Temperature (Colliery Guardian, Sept. 4, 1925, vol. 130, pp. 561-562). An illustrated description is given of the McEwen-Runge system by which pulverised fuel is carbonised whilst in suspension in internally heated towers. It may be operated as a single-stage process or a two-stage process. The two-stage process is carried out in two superimposed steel towers. In the first stage or upper tower the fuel is preheated by means of the sensible heat of the semi-coke leaving the lower tower. In the second stage or lower tower carbonisation is effected. The gases resulting from the primary treatment are neither large in quantity nor of particular value and are dissipated into the atmosphere. In the second stage one-third of the gas manufactured is used for carbonising. The treatment of the dust in each stage occupies thirty-five seconds and a through-put of 210 tons per day is obtained. The product is in the form of finely divided semi-coke, and can be burned in a combustion chamber with a very high combustion efficiency.

S. R. Illingworth, *Low-Temperature Carbonisation* (Gas Journal, June 10, 1925, vol. 170, pp. 741-742). The author describes the difficulties besetting the low-temperature carbonisation of coal, and indicates how they were overcome, drawing his examples from practice adopted at the Treforest Gasworks.

Recovery of By-Products.—A. Brittain, F. M. Roe, and F. S. Sinnatt, *A Study of the Oils (Tars) from the Low-Temperature Carbonisation of Coal* (Fuel, June, July, Aug. 1925, pp. 263-269, 299-307, 337-340). The results are reported of an investigation of the oils or tars produced by the carbonisation of coal at about 600° C. carried out in the Applied Chemistry Department, College of Technology, Manchester, in 1922.

F. S. Sinnatt and J. G. King, *A Study of the Tars and Oils obtained from Coal* (Journal of Society of Chemical Industry, Aug. 14, 1925, vol. 44, pp. 413-424T).

P. Lebeau, *The Thermal Fractionation of the Gaseous Products of the Carbonisation of Solid Fuels* (Chimie et Industrie, July 1925, vol. 14, pp. 10-20). The methods in general use for determining the volatile matter in a coal sample give no indication of the composition of the products evolved at any particular temperature. The actual composition of the gaseous products depends on very small variations of the conditions under which the distillation is carried out. The author surmounted these difficulties by designing an apparatus in which the products could be collected; the temperature could be very closely controlled and varied by very small amounts, and a small sample was used in order to reduce inaccuracies due to the bad heat conduction of the coal. By evacuating the apparatus at -80° C. and subsequently maintaining the temperature steady at various values it was possible to draw off and analyse the constituents which distilled over at each temperature chosen. The author's results, using anthracite, coal, lignite, and peat, are summarised in the paper.

F. Valette, *Industrial Manufacture of Synthetic Alcohol in Coke-Ovens and Gasworks* (Chimie et Industrie, May 1925, vol. 13, pp. 718-721). Two methods of making synthetic alcohol have long been known. During the Great War, when the need was great, alcohol was produced by hydrating acetylene gas to form acetaldehyde which was then hydrogenated to ethyl alcohol. That process is far too expensive for more normal times. The other process uses ethylene as the raw material; it is combined with sulphuric acid to form ethylsulphonic acid, which on hydrolysis and distillation yields ethyl alcohol and the sulphuric acid is regenerated. There are, however, many difficulties to be overcome in the industrial application of this method, and the author describes the process which the Bethune Company have adopted and are preparing to work at their mines. In this process the ethylene will be extracted from the gas to minimise the amount of material reacting or in contact with the sulphuric acid; the absorption of the ethylene by the sulphuric acid will occur under conditions

favouring a maximum absorption and a minimum of acid; the hydrolysis will be carried out in such a way that it may occur quickly and yet leave the acid sufficiently concentrated for use in other ways. Finally, to eliminate loss or waste as far as possible, the residual sulphuric acid will be used in manufacturing ammonium sulphate, the ammonia being a product of another part of this company's plant.

E. Laszlo, *Distribution of the Water of Decomposition Formed in Low-Temperature Carbonisation* (Brennstoff Chemie, 1925, vol. 6, pp. 221-224).

M. Aubert, *A Physico-Chemical Study of Four Liquid Fuels obtained from a Primary Tar Derived from the Extraction Waste of the French Mines in the Sarre* (Chaleur et Industrie, July 1925, pp. 312-319; Aug., pp. 373-379; Sept., pp. 429-431). The four new liquid fuels studied are:

1. A limpid, transparent, mobile liquid, similar to an ordinary petrol, with an ethereal odour suggesting tar oils.

2. A limpid, transparent, slightly yellow liquid, with a less ethereal odour than No. 1, but very similar.

3. A limpid, transparent, bright yellow and very mobile liquid with an odour similar to that of a lamp-oil containing a high proportion of aromatics.

4. A dark brown-black mobile liquid, smelling of creosote.

The paper describes experiments performed on these liquids to determine their physical and chemical properties.

A. Thau, *Distillation of Coal and Tar with the Aid of a Metal Bath* (Glückauf, July 4, 1925, vol. 61, pp. 821-830). The principle of distilling coal by floating it on a bath of liquid lead, so as to maintain a constant temperature, is not new, having been applied by Rolle in Germany in the 'fifties for the distilling of brown coal. Recently the Thermal, Industrial, and Chemical Research Company in London have devised a complete installation for the distillation of coal at low temperature by passing it through a bath of molten lead in a closed vessel. The fuel is fed in from a hopper at one end, and the gases and coke, which float on the surface of the bath, are drawn off by suction through a pipe at the other end. The coke, which is in a granulated condition, falls by gravity into a press, where it is briquetted, and the gas is led through coolers and washers, and the usual by-products are extracted and treated by a similar hot-metal distillation apparatus constructed by the Woodhall-Duckham Company. The Caracristi method, Blümner's method, and the method of Graefe and von Walther, all based on the same principles, are also described; in the two latter processes distillation is carried on under pressure. The last named in particular uses a pressure as high as 40 atmospheres, the distillation being carried on in a closed steel vessel completely immersed in a bath of molten lead.

Use of Waste Heat from Coke-Ovens.—A. Parker, *Utilisation of Waste Heat from Coke-Ovens* (Gas World, 1925, vol. 82, Coking Section,

pp. 34-38). A comparison of the recovery of waste heat from waste-heat ovens, recuperative and regenerative ovens, using a coal containing 30 per cent. of volatile matter, shows that the net energy available from the dry cooling of coke is equivalent to 460 lbs. of steam at 100-lbs. pressure from water at 150° C. From the surplus gas in the waste-heat oven it is 606 lbs., in the recuperative oven 1212 lbs., in the regenerative oven 1666 lbs. Assuming 25 lbs. of steam per kilowatt-hour, the equivalent energy from the various types of ovens is 87·8, 84·2, and 85·0 kilowatt-hours.

IV.—LIQUID FUEL.

Argentine Republic.—J. Rosette, *The Argentine Petroleum Industry* (Petroleum Zeitschrift, 1925, vol. 21, pp. 133-142, 206-214). The author discusses the production, geology, and economic principles of the petroleum industry. The growth of the industry in Argentina is dealt with and particulars of the various grades produced are given.

Burmah.—M. Stuart, *Suggested Origin of the Oil-bearing Strata of Burmah, deduced from the Geological History of the Country, during Tertiary Times* (Journal of Institution of Petroleum Technologists, June 1925, vol. 11, pp. 296-304). A consideration of the geological conditions and earth movements of Tertiary times leading to the formation of the sedimentary deposits which contain the oil-bearing strata found in Burmah.

Estonian Oil Shales.—P. N. Kogerman, *The Present Status of the Oil-Shale Industry of Estonia* (Journal of Institution of Petroleum Technologists, June 1925, vol. 11, pp. 210-223). An account of the further development of the Estonian oil-shales and of the research work thereon is given. Recent investigation with drills has shown that the kukkersite strata worth mining cover an area of 1900 square kilometres, and the known reserves amount to about 3800 million tons. The shales are the richest that have yet been discovered in the world. They are now regularly used as fuel for all kinds of boilers and for domestic heating. An average sample of air-dried shale contains carbon about 35, hydrogen 4·2, oxygen 10, sulphur 1 to 1·4 per cent., and the calorific value of such a sample is 4400 calories (9900 B.Th.U.s).

France.—L. Barrabe and P. Viennot, *Discovery of Petroleum at Gabian, Hérault* (La Nature, 1924, vol. 52, Part 2, pp. 385-387). The discovery of petroleum in this district is regarded as important. The petroleum is present in alternations of cavernous dolomite and sandstone. It is dark brown with a green fluorescence, and on fractional distillation yields 26 per cent. of distillate at 225° to 300° and 70 per cent. above 300°.

Japan.—G. Kobayashi, *Geology of the Oilfields of Japan* (Economic Geology, 1925, pp. 67–82). The three principal oil-fields of Japan are the Hokkaido, the Akita, and the Echigo fields. All three belong to the Tertiary formations, and the oil-bearing strata, their leading fossils, and general structure of the areas are described.

A. H. Redfield, *The Petroleum Supply of Japan* (Engineering and Mining Journal-Press, Aug. 29, Sept. 5, 12, 1925, vol. 120, pp. 325–333, 369–375, 410–419). A survey of the oil resources of Japan, together with statistical information relating to the Japanese petroleum industry. Japan has never been a large producer of petroleum, and the crude oils produced are inadequate not only in quantity but in quality. In an effort to obtain new sources of supply exploration work has been carried out in the Japanese dependencies. The paper concludes with a bibliography of the literature on the Japanese petroleum deposits.

United States.—E. L. Estabrook and C. M. Rader, *History of Production of Salt Creek Oil-Field, Wyoming* (Paper read before the American Institute of Mining and Metallurgical Engineers, Aug. 1925). An account is given of the geology and development of this oil-field, together with particulars of methods of well-drilling, character of the oil, and statistics of production.

V. C. Alderson, *Colorado Oil Shale* (Quarterly of the Colorado School of Mines, Apr. 1925, vol. 20, No. 2, pp. 5–53). A general account of the Colorado oil shale industry.

Mining and Refining of Petroleum.—H. C. George, *Surface Machinery and Methods for Oil Well Pumping* (United States Bureau of Mines, 1925, Bulletin 224). This report deals with prime movers, power-transmitting machinery, and the surface equipment and methods used to pump oil wells.

J. L. Rich, *Possibilities of Petroleum Recovery by Mining* (Engineering and Mining Journal-Press, June 6, 1925, vol. 119, pp. 919–924). The author gives a brief résumé of European methods of mining petroleum, and points out the possible variations of these methods which might be applied to petroleum fields in the United States.

Sir John Cadman, *Refining of Petroleum in South Wales* (Transactions of Institution of Mining Engineers, 1925, vol. 69, pp. 371–382). The paper contains interesting particulars of the procedure adopted in preparing petroleum products for the market at the refinery of the Anglo-Persian Oil Co., Ltd., at Llandarcy.

A. Gradenwitz, *Producing Oil from Swedish Shale* (Engineering and Mining Journal-Press, June 20, 1925, vol. 119, p. 1000). Brief particulars are given of an experimental plant in operation at Kinnekulle, Sweden, for the destructive distillation of shale.

Storage of Petroleum.—K. Kraus, *Selection of Fuel Oil Storage Facilities* (Forging, Stamping, Heat Treating, July 1925, vol. 11,

pp. 250-251). The author advocates the use of steel tanks in preference to other forms of containers. Underground storage offers greater protection from fire and an economy in floor-space, but access to the tank must be possible to allow of painting and the repair of leaks, and this space must be well ventilated.

Use of Petroleum.—J. L. Chaloner, *Developments of British Oil Engines in 1925* (Paper read before the Diesel Engine Users' Association: Engineer, Apr. 24, 1925, vol. 139, pp. 456-457). The author reviews the various types of British oil engines in use at the present time for power purposes, with special reference to the engines exhibited at the British Empire Exhibition in 1924. The simplification of design, the greater use of steel castings, the standardisation for mass production and improvements are helping to make the oil engine in every way a competitor of other forms of power generators.

J. S. S. Brame, *Motor Fuels* (Journal of the Royal Society of Arts, 1925, vol. 73, Aug. 28, pp. 920-929; Sept. 4, pp. 930-941; Sept. 11, pp. 942-954). The author includes under the title of motor fuels, petrol, benzole, and power alcohol, and he discusses their production and use from both the economic and technical points of view.

Hydrogenation of Coal.—F. Bergius, *The Liquefaction of Coal* (Zeitschrift des Vereines Deutscher Ingenieure, Oct. 17, 1925, vol. 69, pp. 1313-1320). The author describes his experiments with the object of liquefying coal by direct hydrogenation, and the rotary autoclave now used with the object of securing a better mixing of the gas and coal. Over 2000 trials have been made by the author and his collaborators, and the results are presented in tabular form. The Berginised oil recovered from ordinary bituminous coal averages 40 to 60 per cent. by weight of the raw coal, and the organic insoluble coal substances run from 10 to 26 per cent. The best results are obtained with hydrogen pressures of 100 atmospheres at temperatures of 450° to 480° C. At lower pressures the proportion of insoluble residues is higher, and at 50 atmospheres coke is formed and no oil.

H. G. Shatwell and A. R. Bowen, *The Hydrogenation and Liquefaction of Coal* (Fuel, June 1925, vol. 4, pp. 252-255). The author deals with the hydrogenation and destructive distillation of Arley coal. The volatile matter varies from 30·1 to 36·33 per cent. The coal used consisted of clarain, the small amounts of fusain present in the original sample being separated as far as possible and discarded. Experiments were made in hydrogenation and heating under pressure with nitrogen. In both experiments 200 grammes of coal and 400 grammes of phenol were heated in a rotating autoclave over a period of four days. A fundamental difference is brought about by the use of hydrogen and of an inert gas. Although the temperatures, initial pressures, and times of heating were almost identical, the pressure changes were considerable. During hydrogenation there was a total loss in pressure of 33 atmo-

spheres, whereas with nitrogen an increase of 8 atmospheres occurred. Hydrogen under pressure has a profound influence in causing decomposition of the coal, since the yield of gas is higher than that obtained in other experiments with other gases.

H. I. Waterman and J. N. J. Perquin, *Berginisation of Dutch Coal* (Journal of Institution of Petroleum Technologists, Aug. 1925, vol. 11, pp. 374-378). The coal used for the experiments contained moisture 1.55, ash 8.7, carbon 79.5, hydrogen 4.8, and sulphur 1.1 per cent. By treatment in an autoclave at 430° to 450° C., with hydrogen at a pressure of 110 kilogrammes per square centimetre the coal was transformed into oil containing high percentages of gasoline and kerosene equal to about 40 per cent. of the weight of the coal. Some carbon remained in suspension, but this settled after a while.

Description of the Bergius Process of Liquefying Coal (Mining Journal, Oct. 10, 1925, vol. 151, pp. 790-791). An abstract in English of an account of the process by H. Wolbling of the Technical High School, Charlottenburg, published in Die Metallbörse, Sept. 23, 1925. Some of the details, lacking in earlier accounts, are supplied.

V.—ARTIFICIAL GAS.

Gas-Producers.—*The Strache Mixed-Gas-Producer* (Gas Journal, July 1, 1925, vol. 171, pp. 48-49). An abstract (in English) is given of a communication by A. Grebel to the Société Technique de l'Industrie du Gaz en France, which is an adaptation of H. Strache's paper recently read in Warsaw.

P. Appell, *Notes on Present Tendencies in the Choice of Gas-Producers* (Chaleur et Industrie, Apr. 1925, pp. 200-201). In the past cylindrical gas-producers have been in greater favour than the rectangular types, because mechanical grates for the automatic removal of ashes from the furnace were more easily adapted to them. This difficulty has now been overcome, and the author is of opinion that in general the rectangular form is superior to the cylindrical. He stresses the point that some form of automatic ash-clearing grate is essential because hand-clearing of the grate leads to irregular working of the producer with consequent variations in the gas produced. He gives figures in support of this contention.

Producer Practice.—R. Hennecke, *Generation of Steam for Gas-Producers, using the Cooling Water from the Furnaces* (Stahl und Eisen, Sept. 17, 1925, vol. 45, pp. 1602-1604). An arrangement is described whereby the steam for blowing into a gas-producer is generated by burning a small quantity of fuel gas, the hot products of which are used to evaporate a regularly measured supply of water, the steam from which mixes with the air supply for blowing the producer. The

cooling water from the furnaces at 45° to 60° C. is nearly warm enough without further heating to generate the necessary steam in the vessel, the pressure of the vapour being lower than that of the atmosphere. The degree of saturation of the air with steam averages about 90 per cent.

B. Osann, *Trials in Determining the Most Suitable Composition of Producer-Gas by Varying the Depth of the Fuel Bed and the Quantity of Steam* (Stahl und Eisen, Sept. 10, 1925, vol. 45, pp. 1566-1568). Analyses of the coal used show that it was a good gas coal containing 75.24 per cent. carbon, with 6.11 per cent. ash and 3.98 per cent. moisture, with a heat value of 7559 calories. In one set of trials the depth of fuel bed was varied from 20 to 40 inches, the steam being kept constant at 0.3 kilogramme per kilogramme of coal. In the second series of trials the fuel bed was kept at a depth of 30 inches and the steam supply was varied from 0.1 to 0.6 kilogramme per kilogramme of coal. In the first trials the gas attained the maximum calorific value of 1355 calories with a depth of fuel of 32 inches and 0.3 kilogramme of steam, the composition of gas showing CO 29.4 and H_2 11.4 per cent. In the second series the best results were obtained with steam at 0.4 kilogramme and depth of fuel at 30 inches, the gas having 1324 calories, and containing CO 28.4 and H_2 12.0 per cent.

W. A. Dunkley, *Bituminous Coal as Generator Fuel for Large Water-Gas Sets with Waste-Heat Boilers* (United States Bureau of Mines, 1925, Technical Paper 335). The author summarises a number of tests of the use of bituminous fuel in the production of water-gas, and discusses some economic phases of the process.

Regeneration of Combustion Gases (Gas- und Wasserfach, Feb. 7, 1925; Gas Journal, Apr. 22, 1925, vol. 170, pp. 255-256). The proposal had recently recurred that a proportion of the combustion gases in producer practice might be withdrawn as they enter the recuperator, and that, instead of steam, gases containing CO_2 should be introduced with the combustion air under the producer grate. It was suggested that a considerable fuel economy could be thus effected. In this paper the subject is dealt with mathematically, and the whole of the calculations of the heat processes involved in the regeneration of waste gases from a producer are set forth. The conclusion arrived at is that, as compared with ordinary steam injection, no advantage is gained by the method.

The Enrichment of Coal-Gas (Colliery Guardian, Oct. 2, 1925, vol. 130, p. 799). The results of a series of investigations carried out at the Fuel Research Station on the effect of introducing steam at the bottom of vertical gas retorts, show that, though the thermal yield of gas is increased, its calorific value falls as the amount of injected steam rises. This fall in the calorific value of the gas limits to some extent the application of steaming. The effect of oil injection was also studied. The injection of oil produces an increase in both gas calorific value and gaseous therms. No additional heat is required for the setting. Further increases in amount of oil injected give increased yields of

gaseous therms, but the increase in calorific value is not in proportion. The upper practical limit of oil injection apparently lies between 10 and 15 gallons per ton of coal. Above this value the gas contains an excess of condensible hydrocarbons, and some oil passes over into the tar. The yields and qualities of coke, tar liquor, and ammonium sulphate are not appreciably affected by oil injection.

Use of Coke-Oven Gas.—F. M. Washburn, *Calculations of the Combustion of Coke-Oven Gas* (Blast-Furnace and Steel Plant, May 1925, vol. 13, pp. 200–202). The chemical equations for combustion of coke-oven gas are given, with a set of tables for the calculation of the amounts of the various gases produced by, or required for, the combustion of coke-oven gas. Equations are derived for calculating the relation between the percentage of oxygen in the flue gas and the percentage of excess air, and also between the percentage of carbon dioxide and percentage of excess air, and curves are given of these relationships. The methods and equations are applicable to any commercial combustible gas, such as producer-gas, blast-furnace gas, water-gas, &c., and any constituents not accounted for in the article can easily be included if needed.

C. Berthelot, *The Centenary Congress of the Gas Industry in France: Views on the Employment of Coke-Oven Gas for Town Lighting* (Revue de Métallurgie, Mémoires, Feb. 1925, vol. 22, pp. 107–118). The use of coke-oven gas has not made the same progress in France as it has elsewhere, and whereas in England, Germany, and the United States even large towns are lighted by this means, the number of coke-oven plants in France making town gas is small. It is a most suitable illuminating fuel, and coal with only 18 per cent. of volatile matter can be economically gasified in coke-ovens. It must, however, be free from salt, which attacks the coke-oven linings. The silica brick obtained from Czecho-Slovakia has proved very resistant and gives excellent results. Its composition and behaviour are described, with tables of the results obtained.

Use of Blast-Furnace Gas.—E. C. Evans, *Utilisation of Blast-Furnace Gas* (Fuel Economy Review, June 1925, vol. 4, pp. 22–26). Perfect efficiency in blast-furnace gas utilisation involves the following three factors: (1) The use of clean gas, (2) efficient pressure regulation, and (3) correct burner design. The advantages of clean gas for boilers and stoves are pointed out. Dry cleaning systems have the advantage of preserving the sensible heat of the gas. At an electrical cleaning plant in operation in the country treating $3\frac{1}{2}$ to 4 million cubic feet of gas (N.T.P.) per hour, the gas enters at 316°C . with a dust content varying from 3 to 7 grammes per cubic metre, and leaves with about 0.3 gramme. The adoption of this plant has allowed of an increase in the maximum blast temperature from 1300° to 1600°F ., while no cleaning of the stoves has been necessary for over two years. No burner has yet been designed which can be regarded as absolutely

efficient in respect to the correct proportioning of gas and air under variable pressure conditions. The simplest method of obtaining uniformity in gas pressure is by the installation of a gas-holder. This system has been adopted at some of the Continental works. The erection of gas-holders, however, involves a very considerable capital outlay, and as a substitute automatic pressure regulators have been installed at a number of works at suitable points on the gas-delivery system. Excellent results have been obtained by supplying both gas and air under constant pressure. In the United States this system has been installed at a number of plants by the adoption of pressure burners of the Steinbart type combined with Hagan regulators. The apparatus has been applied both to boilers and stoves; in boiler furnaces the burner is designed to give a short flame, whilst in the stoves the burners provide a long flame.

O. C. Callow, *Power Generation by Blast-Furnace Plant* (Iron and Steel Engineer, 1925, vol. 2, pp. 242-246). The use of blast-furnace gas and coke breeze under boilers is dealt with. The disposal of surplus power produced by an isolated furnace is discussed, and the advantage of having two furnaces in operation, thus reducing the number of low steam periods, is pointed out.

C. H. S. Topholme, *Power from Blast-Furnace Gas* (World Power, Aug. 1925, vol. 4, pp. 90-93). A description of some of the ways in which blast-furnace gas is used.

Power in Iron and Steel Works. M. Derclaye, *Evolution of the Utilisation of Energy in Gas and Steam Plants in the Iron and Steel Industries* (Revue de Métallurgie, Mémoires, July 1925, vol. 22, pp. 435-449). The author seeks to ascertain the amount of energy available at the different stages of blast-furnace practice after deducting the gas necessary for the hot-blast stoves, the power required for blowing, and that necessary for the furnace auxiliary services and the central power station. He bases his calculations on a furnace burning 100 tons of coke and producing 100 tons of pig iron per twenty-four hours, the coke containing 83.2 per cent. of carbon, and finds that for the combustion of 100 kilogrammes of coke per twenty-four hours, 326 cubic metres of air are required per minute. The gas required for heating purposes is next discussed, taking the Cowper stoves as 60 per cent. in one case and as 85 per cent. in another. The gas remaining available after these requirements have been met will be from 10,159 cubic metres to 12,140 cubic metres respectively. The efficiency of gas-engines is 30 to 42 per cent. greater than a boiler-turbine system, particularly when heavy driving is required. After going into detail as regards all the requirements, a gas balance-sheet is given, derived from the actual case of a French works making 34,412 tons of basic pig iron per month, and using 1000 kilogrammes of coke per ton of pig. The Cowper stove efficiency is 60 per cent., and the pressure of the blast 35 centimetres of mercury.

F. Schulte, *Gas-Fired High-Pressure Fire-Tube Boiler* (Glückauf,

Sept. 12, 1925, vol. 61, pp. 1153-1157). The author gives details of a new design of fire-tube boiler at the Duisburg Copper Company's works. It consists of two steel-plate cylinders, about 11 feet diameter each, placed horizontally one above the other. The upper cylinder is constructed with five corrugated fire-tubes fitted at one end with a gas inlet and burner, each tube being about 2 feet diameter. The lower cylinder is provided with 158 4-inch smoke tubes, through which the hot gases of combustion return, and they then pass through an economiser for preheating the combustion gas, and thence are drawn off by a suction fan to the chimney. The boiler pressure is 18 atmospheres, the thickness of the boiler plates a bare $1\frac{1}{4}$ inch, and using blast-furnace gas preheated in the economiser the evaporation is 26.6 to 36.4 kilogrammes per square metre of heating surface. The boiler plates are of special steel, the composition of which is not stated.

H. Wolff, *Progress in the Supply of Steam Power to Ironworks* (Stahl und Eisen, July 16, 1925, vol. 45, pp. 1225-1232). Whereas the gas-engine has now about reached the limit of its technical and economic development, there is still room for further progress in the use of steam for power purposes. The author discusses the lines on which progress is promising, such as an increase in boiler efficiency to 85 or 87 per cent. by suitable gas-firing, giving a steam generation of 40 kilogrammes per square metre of heating surface; raising the pressure to the highest limit compatible with economy, or, say, about 35 atmospheres; the use of live steam for heating the feed-water; the use of waste heat for preheating the air for combustion, and improvement in the design of turbines, especially at the high-pressure ends.

H. Bleibtreu, *Important Improvements in the Design of American Steam Boilers* (Stahl und Eisen, Sept. 10, 1925, vol. 45, pp. 1549-1555). The author discusses the subject under the following heads: Means for cooling the brickwork of the walls; mixing of the gases of combustion with secondary air; dimensions of combustion chambers and the process of combustion, using powdered fuel; firebricks, bonding, and staying of the walls, and the construction of the firing chamber as an integral part of the boiler.

J. G. Worker, *Higher Thermal Results in the Boiler Room, and the Relation between Efficiency and Economic Values* (Proceedings of the Engineers' Society of Western Pennsylvania, Mar. 1925, vol. 41, pp. 33-55). The author briefly surveys the development and improvement of mechanical stokers, and he is of opinion that greater efficiency of combustion can be attained by means of mechanical stokers than by the use of pulverised fuel. He considers the subjects of heat loss and steaming capacity, and on these points he is also in favour of the mechanical stoker, which he describes in his conclusion as inherently the simplest and most economic system of extracting heat from coal. He mentions that 12 million horse-power of stokers are installed in America to-day, and they are being increased at the rate of 750,000 horse-power a year.

A. J. T. Taylor and F. A. Wettstein, *The Ruths Steam Accumulator*
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(Mechanical Engineering, Aug. 1925, vol. 47, pp. 619-623). The Ruths steam accumulator is based on the principle of storing in a large quantity of water under pressure and at saturation temperature the heat energy of steam, and releasing this energy in the form of steam under decreasing pressure. The accumulator is, in effect, the heat flywheel of the boiler plant. The construction of the accumulator is fully described, and the manner in which it and the automatic controlling valves work is explained. This system has so far found its widest application in pulp and paper works, textile, chemical, and sugar factories, where steam is consumed for process work. In cases where the steam is chiefly used for power the problem is slightly different. Here the accumulator has to supply superheated steam and not dry saturated steam as in the former cases. This end is attained by the use of a second accumulator, working on the Siemens regenerator principle, in which plates of cast iron absorb the superheat. An installation of this kind has been proposed for an iron and steel works on the Continent, where the energy required in the works is mainly supplied by the coke with which the blast-furnaces are charged. The three blast-furnaces are operated with an output of about 1500 gross tons per twenty-four hours, and the furnace gases contain about 63 per cent. of the heat supplied in the coke. Some of this is used in gas-engines to produce electricity and some for the generation of steam. The average steam consumption is 125,000 lbs. per hour, but this may drop to 30,000 or rise to 200,000 lbs. per hour, and to deal with these variations a large coal-fired boiler-house has been added; but it is estimated that 15 per cent. of the furnace gas has to be wasted owing to the variations of supply and demand. Similarly, the average demand for electricity is 16,000 kilowatts with fluctuations amounting to 4000 kilowatts. All this is to be rectified by the installation of two Ruths accumulators, one superheat accumulator, and a 10,000 kilowatts peak load turbine, which will be able to store the energy in 60,000 lbs. of steam and re-deliver it as an electrical peak load of 4000 kilowatt-hours. The steam accumulators will each be 12 feet diameter and 6 feet long; the superheat accumulator will be 6 feet diameter, 35 feet long, and contain 135 tons of cast iron.

VI.—COAL WASHING AND HANDLING.

Coal Handling.—*Coal-Handling Plant at East Greenwich Power Station* (Electrical Review, May 29, 1925, vol. 96, p. 872). A brief description and line drawings are given of the apparatus recently installed at the East Greenwich Power Station. A system of grab transporters and belt conveyors unloads the coal from colliers and distributes it into the bunkers over the boiler-house, or alternatively into storage bunkers. Coal which is too large for use in the chain-grate stokers is passed through Jeffrey single-roll crushers; and all coal passing to the boiler-house or bunkers are automatically weighed. The

drive on the long inclined belt is arranged so as to give over 360° actual contact between the driving pulleys and the belt, thereby reducing by about one-half the ultimate stress in the belt. The total rated capacity is 200 tons per hour, but this figure has been considerably exceeded in practice.

C. H. S. Tupholme, *Fuel Conveyors for Power Plants* (World Power, July 1925, vol. 4, pp. 30-33). An outline of some modern fuel conveyors.

Coal Screening.—E. A. Holbrook and T. Fraser, *Screen Sizing of Coal, Ores, and Other Minerals* (United States Bureau of Mines, 1925, Bulletin 234). The report outlines present-day practice in coal screening, and deals in detail with the factors involved in the efficient operation and design of screening plants. The four general types of screening machines dealt with are: (1) Stationary gravity screens; (2) revolving screens; (3) shaking screens, riddles, or jiggers; and (4) vibrating screens.

New Screens at Rock Colliery (Iron and Coal Trades Review, May 15, 1925, vol. 110, p. 793). The new coal-screening plant of the Rock Colliery, Glyn Neath, for dealing with anthracite coal is described and illustrated.

S. B. Berrisford and W. H. Berrisford, *Coal Screening* (Transactions of the Institution of Mining Engineers, 1925, vol. 69, pp. 282-307). The paper discusses some of the principles in the design of machinery for the sorting, cleaning, and sizing of coal.

Coal Washing.—H. J. Thomas, *Cleaning of Small Coal at Collieries* (Transactions of the Institution of Engineers, Australia, 1922, vol. 3, pp. 3-25). The dry method of separation is described, and three types of wet coal-washing machines—the trough washer, the inverted cone Robinson washer, and the jig washer—are dealt with, their construction and operation being explained. Mention is made of coal-washing plants recently installed in New South Wales, and the Lührig nut-washing plant is described in detail.

W. McLaren, C. N. Kemp, and J. L. Thomson, *The Scientific Control of Coal-Washing by the Combined Application of Ash-Characteristic Curves and X-Ray Examination* (Transactions of the Institution of Mining Engineers, 1925, vol. 69, pp. 315-338).

B. F. Haanel, *The Trent Process for Purifying Coals with High Ash Contents* (Chaleur et Industrie, July 1925, pp. 339-344). The author describes the process and tabulates the results of experiments carried out on various types of coal.

W. Gross, *The Preparation of Coal* (Zeitschrift des Vereines Deutscher Ingenieure, July 25, 1925, vol. 69, pp. 975-980). The various methods of cleaning and washing coal are described and illustrated. In Germany coal-washing plants with jigs and settling tanks are usually employed. The author deals with other processes, such as the flotation method, the oil amalgam process, and centrifugal cleaning and drying.

R. A. Henry, *The Theory of the Wet Washing of Coal* (Revue Universelle des Mines, June 1, 1925, vol. 6, pp. 246-278). The author sets out the phenomena manifested in the washing of coal by means of flowing water and the laws governing these phenomena.

Largest Coal-Washing Plant in the United Kingdom (Iron and Coal Trades Review, Oct. 16, 1925, vol. 111, pp. 600-601). An illustrated description is given of the coal-washing plant recently put into operation at the Marine Colliery of the Ebbw Vale Steel, Iron, and Coal Co., Ltd. The plant has a capacity of 300 tons per hour.

Coal Drying in the Carpenter Centrifuge (Iron and Coal Trades Review, Sept. 4, 1925, vol. 111, pp. 359-360). An entirely novel coal-drying machine has recently been installed at the Nunnery Colliery, Sheffield. This machine, known as the Carpenter Centrifuge, is described and illustrated, and particulars are given of operating results. It comprises a stepped truncated cone, driven by a vertical shaft, and enclosed in a circular casing. The coal, which is fed into a hopper at the top, is thrown by centrifugal force against screens, thus overcoming the surface tension and separating the liquids from the solids. The coal is kept broken up by means of serrated teeth.

Spontaneous Combustion.—J. I. Graham and T. D. Jones, *Spontaneous Combustion in the South Wales Coalfield* (Transactions of the Institution of Mining Engineers, 1925, vol. 69, pp. 413-427). The authors have carried out an investigation of the phenomenon of spontaneous combustion in coal-seams in South Wales. It is concluded that spontaneous combustion in the South Wales coalfield depends more upon the physical factors involved, such as the thickness of the seam, the method of working, and the friable nature of the coal, than upon the presence of any portion of the seam which is readily oxidisable at ordinary pit or goaf temperatures. In cases where spontaneous combustion is met with in seams of more or less normal thickness, the initiating cause appears to be the oxidation of pyrites present in a finely disseminated form. When fires have occurred in abnormally thick coal, it seems possible that the broken coal itself may have been responsible in the primary stages, but there is no doubt that a local accumulation of pyritic matter would very largely accelerate oxidation of the coal, which, once the temperature reached the neighbourhood of 100° C., would itself carry on the process to the stage of active combustion.

J. Lomax, *Further Researches on the Various Types of Pyrites in Coal, Especially in Relation to Spontaneous Combustion* (Paper read before the Manchester Geological and Mining Society: Colliery Guardian, May 29, 1925, vol. 129, pp. 1317-1318). The author has carried out a microscopical investigation of various forms of pyrites or iron-disulphide found in coal, their origin and probable effects in relation to spontaneous combustion.

PRODUCTION OF IRON.

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I.—MANUFACTURE OF PIG IRON.

Blast-Furnace Construction.—*Inwall Cooling for Blast-Furnaces* (Iron Age, Aug. 27, 1925, vol. 116, pp. 530–531). Particulars are given of the Dovel system for cooling the inwalls of blast-furnaces. It consists essentially of a series of water-cooled plates, carried by the shell of the furnace. A section drawing is given showing the system as applied to the new blast-furnace at Ymuiden, Holland.

Blast-Furnace Practice.—W. D. Brown, *A Study of Carbon used in Blast-Furnace otherwise than before the Tuyeres* (Blast-Furnace and Steel Plant, June 1925, vol. 13, pp. 236–238). The carbon used otherwise than at the tuyeres may be divided thus :

A. That required to reduce silicon, manganese, phosphorus, and sulphur.

B. That required to reduce the last trace of iron oxide. The indications are that at least 98 per cent. of the iron is reduced by carbon monoxide below 1800° F.

C. Impregnation of the pig iron, which absorbs 0.04 lb. carbon per lb.

D. "Solution loss" : at about 1520° F. limestone begins to give off its CO₂ and this reacts with carbon, yielding carbon monoxide.

E. Some carbon is absorbed in the decomposition of steam arising from the charge, &c.

The author gives a table of figures showing the amount of carbon required for each of these reactions.

S. P. Kinney, *Combustion of Coke at the Tuyere Level of the Blast-Furnace* (Blast-Furnace and Steel Plant, June 1925, vol. 13, pp. 243–247). A series of gas samples was taken at the tuyere plane of fourteen blast-furnaces in 1922, and the results from these showed that the combustion of the coke in the hearth was complete at a distance of 32 to 40 inches

from the nose of the tuyere measured in a horizontal line between the centre of the nose of the tuyere and the centre of the furnace at the tuyere level. The present report deals with the extent of penetration of the combustion zone with variation of the amount of air blown. Two furnaces were selected for the investigation, and the blowing pressure varied from normal (14 lbs.) pressure down to 1 lb. pressure. Tables and graphs of the gas analyses made are given, and the conclusion arrived at is that the extent of penetration of the combustion zone at the tuyere level is a constant, not depending on the amount of air blown.

S. P. Kinney, *Iron Hottest at Middle of Cast* (Iron Age, Aug. 20, 1925, vol. 116, pp. 466-467, 514-515). Approximately 1000 temperature readings were observed at the tuyeres and of the metal and slag of a blast-furnace in the southern district of Alabama, while producing foundry iron. The results are discussed, and a comparison is made with results obtained at a number of other furnaces and at the Bureau of Mines experimental furnace. The temperature of the slag remains constant with an increase of blast temperature; this is in agreement with Johnson's "free-running" theorem. The trend of tuyere temperature in relation to increasing blast temperature is indefinite—the data indicating that there is a slight increase, 0.15° per degree increase in blast temperature. Metal temperatures increase 0.28° per degree increase in blast temperature. The silicon content of the metal increases with metal temperature. The metal temperature at the middle of a cast has an average increase of 24° C. above the temperature of the metal at the beginning of the cast, and is 13° C. higher than the average temperature of the cast. The application of the empirical equations of Royster and Joseph for determination of metal temperatures and silicon content of metal shows results too high for the former and too low for the latter in comparison with actual observations.

S. P. Kinney, *Material and Heat Balance of a Southern Foundry Furnace* (Blast-Furnace and Steel Plant, July 1925, vol. 13, pp. 272-277). A most elaborate investigation was carried out by which it was possible to calculate the quantities of all the ingredients of the charges going into a particular furnace. Also a heat balance was made, and by calculations the distribution of the heat put into the furnace among the various reactions within the furnace was determined, together with the nature and amount of heat losses. The results obtained are set out in eight comprehensive tables, and comparisons are made with four other furnaces and with the average of fourteen northern furnaces. The author concludes that certain quantities of heat are necessary for the reduction of the oxide to metal, and it is practically a constant in all furnaces. But a comparison of heat balances of southern and northern furnaces shows that more heat is required in the south because, owing to the ores being less rich, there is a larger amount of gangue to be slagged off; also this larger slag mass carried more "lost" heat away with it. The author shows that when the heat required to reduce enough oxide to form a ton of metal has become only, say, 30 per cent. of the total

heat required in the process, it is found that the material is low-grade ore requiring large quantities of flux and fuel. At this point it will be necessary to turn to some other more economical means of operation.

J. Thibeaup, *Study of CO, CO₂, and H₂: Application to Blast-Furnaces and Producers* (Revue Universelle des Mines, 1925, vol. 6, pp. 313-348; vol. 7, pp. 25-42, 74-92, 155-168, 186-199). These notes were originally written in 1910-1914. The author has attempted to find explanations of certain phenomena and anomalies that he has met with in the course of his experience with blast-furnaces and producers. In this paper he deals with the following subjects: reversible reactions, the quantitative laws of equilibrium, equilibrium between C, CO, and CO₂, the free energy of a chemical reaction, combustion of coal with oxygen, and the proportions of CO and CO₂ formed, a subsection of this latter being the combustion of coal with atmospheric air. In the case of blast-furnaces he considers the combustion of carbon before the tuyeres, the temperature before the tuyeres, and the theory of the reduction of the oxides of iron. Accounts of experimental researches made on blast-furnaces and the results obtained are given in detail, the composition of the gas and the working of blast-furnaces are discussed, and a calculation is made of the costs for "ideal" working. The whole treatment of the subject is mathematical, and the author deduces from the figures which he puts forward the lines along which improvements may be made, and suggests innovations modelled on these deductions.

H. Kamura, *Reduction of Ferric Oxide and Iron Ores by Hydrogen* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 279-297).

D. Sillars, *Recent Views of Blast-Furnace Functions* (Journal of the West of Scotland Iron and Steel Institute, Session 1924-25, vol. 32, pp. 52-59). The author discusses the views of other investigators as to the manner in which fuel is consumed in the blast-furnace. To secure the thermal advantage of indirect reduction it must take place at a temperature lower than that at which the solution of carbon becomes appreciable to ensure that the CO₂ formed passes away at the top of the furnace unchanged. Indirect reduction possesses the mechanical advantage of being a gaseous reaction. Carbon monoxide can and does diffuse into the lumps of ore, while direct reduction can only take place at the contact points of the solids. Probably the best measure of combustibility is that of Korevaar, who determines it by the size of the zone in which the resultant products are saturated with carbon. In relation to the hearth of a blast-furnace the combustibility of the fuel is inversely proportional to the distance from the tuyeres at which oxygen and carbon dioxide just disappear. Combustibility is, therefore, a measure of the speed of the combination of oxygen and carbon to form carbon monoxide.

E. C. Evans, *Fuel in the Iron and Steel Industry* (Journal of the West of Scotland Iron and Steel Institute, Session 1924-25, vol. 32, pp. 66-78). The fuel consumption in blast-furnaces in the United

Kingdom is compared with practice abroad, and the factors governing fuel economy in the blast-furnace are discussed. A study of the furnaces of which exact figures have been obtained indicates that modern British furnaces with similar burdens to those in America, although working with lower outputs and higher fuel consumptions than American furnaces, are, when all factors are taken into consideration, producing pig iron with a comparable fuel consumption.

H. Lent, *Temperature and Analysis of the Gases at the Throat of a Modern Blast-Furnace* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1149-1152). The furnace gave an average yield of 774 tons of pig iron per day, with a consumption of 905 kilogrammes of coke per ton of pig iron. The coke had 3 per cent. moisture and 9.2 per cent. ash. The burden consisted of minette 15, slag from the acid open-hearth 10, Wabana ore 10, Grängesberg ore 45, limonite 7.5, Kiruna ore 12.5 per cent., and lime equal to 9 per cent. of the weight of the ore. The gas from the centre of the furnace showed CO 34 to 36 and CO₂ 6 per cent.; at the edge the CO was 3 to 4 per cent. less than in the centre and the CO₂ was 2 to 3 per cent. higher. During tapping the gas increased considerably in CO₂, the composition being about :

	Per Cent.
CO	45
CO ₂	30
H ₂	9.1

Normally the hydrogen was about 1.5 per cent.

A. Wagner, *The Use of Small Coke in Smelting* (Glückauf, June 6, 1925, vol. 61, pp. 700-706). Information collected from a number of iron-works confirms previous experience, namely, that it is advantageous to use small coke in the blast-furnace, so long as it is hard and of good resistance to compression. Coke passing a 20-millimetre sieve appears to give the best results both in America and Germany.

A. Wagner, *Use of Small Coke in the Blast-Furnace* (Stahl und Eisen, June 11, 1925, vol. 45, pp. 929-938). A comparison is made between German and American practice in regard to the grading of coke for use in the blast-furnace, and a number of data concerning the size of coke used in German blast-furnaces are published. In many works the coke is screened, but there is considerable diversity in the size of the coke at different furnaces. In general the size ranges from $\frac{3}{4}$ to 4 inches. Small coke of $\frac{3}{4}$ to 1 inch gives good results in furnace working, provided it is hard and of a good compressive strength.

H. Braune, *The Formation of Cyanide in the Blast-Furnace Process* (Stahl und Eisen, Apr. 16, 1925, vol. 45, pp. 581-582). In attempting to form cyanide compounds by heating carbon and nitrogen it was soon discovered that the yield was very little even at very high temperatures. It is only with the aid of a catalyst that the formation of cyanide takes place on a considerable scale, and of the various catalysts available unreduced iron compounds have proved to be the most suitable and can be applied in the form of ordinary ore. Observations were carried out

on various Swedish blast-furnaces manufacturing forge iron. The proportion of ore in the burden in all the furnaces was comparatively high, but in other respects the working of the furnaces differed. Those which were worked slowly always produced good Lancashire pig. In the case of the furnaces which were driven more rapidly a good forge iron was at first produced, but beyond a certain speed of driving the product no longer worked up into forge iron, but became brittle and useless. Consideration of the catalytic conditions explains the cause of this change in the pig iron; when the furnace works slowly the reduction of the ore is completed a long way above the tuyeres, the unreduced iron compounds are unable, therefore, to exercise their effect as catalysts for the formation of cyanide from carbon and nitrogen at the tuyere level. The amount of cyanide that was formed was so negligible that the nitrogen in the pig iron did not exceed an average of 0.004 per cent. When the furnace was driven faster this good quality of iron was maintained until the point when the end reduction of the iron took place immediately above the tuyeres, and the unreduced iron compounds then came into effect as catalysts and a high yield of cyanide followed, noticeable from the fact that, in tapping, potassium cyanide ran out with the slag, burning with a blue flame. The nitrogen content of the pig iron in such cases rises to 0.020 per cent. This explains the sudden change in the quality of the pig iron, and indicates that the quality of Swedish charcoal iron depends largely upon the slow working of the furnace in order to prevent the unreduced iron compound from exercising any catalytic effect. In coke blast-furnaces the same occurrence has been noted, namely, that where cyanide was freely formed the iron when converted became useless and brittle.

S. P. Kinney and E. W. Guernsey, *The Occurrence of Alkali Cyanides in the Iron Blast-Furnace* (Industrial and Engineering Chemistry, July 1925, vol. 17, pp. 670-674). The authors discuss the probable mode of formation of alkali cyanides in the blast-furnace and give the results of an investigation to find out how the cyanide concentration is distributed within the furnace. They put forward a tentative suggestion for the recovery of part of the alkali cyanides.

H. von Schwarze, *The Blowing In, Damping Down, and Blowing Out of Blast-Furnaces* (Stahl und Eisen, Apr. 23, 1925, vol. 45, pp. 609-613). The methods pursued at various works in the Ruhr and the Saar districts in the blowing in, damping down, and blowing out of blast-furnaces are described. In one instance a furnace was extinguished by filling up with a damping-down burden containing 20 to 50 per cent. less ore than the normal amount, while using the same or a larger quantity of coke. The tuyeres were then removed and the holes and all other openings including the bell and gas down-take were hermetically sealed. The furnace was then filled with gas to a pressure of $2\frac{1}{2}$ to $3\frac{1}{4}$ inches mercury column, which appeared to quench the coke. After thirty days the gas pressure was removed and the work of building wall cooling boxes was begun. The admission of air, however, caused ignition of

the pyrophoric carbon and coke dust, and water had to be used for extinguishing the mass which began to glow.

S. P. Kinney, *Furnace Lining Wears Unevenly* (Iron Age, June 4, 1925, vol. 115, pp. 1639-1640). The author gives the results of an investigation of a 300-ton blast-furnace, which includes a study of the reactions taking place at various levels. Some interesting information was obtained as to the thickness and temperature of the furnace lining at a number of points between the tuyere level and the stock line after the furnace had been in operation for fourteen months. The temperature was taken at certain distances from the inside of the steel shell to the inwall.

J. L. Keenan, *Blast-Furnace Practice in India, with Special Reference to Economy in Coke Consumption* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 45-63).

O. Wehrheim, *The Blast-Furnaces of the United States and their Technical Organisation* (Revue de Métallurgie, Mémoires, May 1925, vol. 22, pp. 291-301). The translation into French of a series of articles describing American blast-furnace practice, which has appeared in *Stahl und Eisen*, 1924, vol. 44, pp. 1005-1012, 1074-1080, 1105-1112, and 1138-1145.

F. T. Sisco, *The Manufacture of Iron and Steel* (Transactions of the American Society for Steel Treating, Aug. 1925, vol. 8, pp. 191-240). The first of a series of articles dealing with the metallurgy of iron and steel. Details of the furnaces used, their operation, and the smelting or refining accomplished, are described briefly in non-technical language.

Enriched Blast.—A. Bruninghaus, *Manufacture and Use of Oxygen-Enriched Air in Ironworks* (*Stahl und Eisen*, May 14, 1925, vol. 45, pp. 737-746). The author describes various methods for the separation of oxygen, and presents figures showing that the cost of production of 1 cubic metre of oxygen, with a plant working on a fairly large scale, is about $\frac{3}{8}$ ths of a penny. The use of oxygen-enriched air is therefore well within the limits of economic possibility, and it can be applied with advantage for a number of special purposes, but in general no great advantage is to be looked for from its use. There are, however, certain processes which might be developed by using enriched air—for example, furnaces heated with such air could give results equal to any electric furnace, and might be used as a substitute for such. In converter practice, however, the whole conditions are altered if enriched air is used, and much experimental work requires to be done before it can be demonstrated whether any advantage is to be gained by its use.

W. C. Buell, jun., *Some Aspects of Oxygen Enrichment of Combustion Air in Heating Furnace Practice* (Proceedings of the Engineers' Society of Western Pennsylvania, May 1925, vol. 41, pp. 133-143). The paper presents a study of the theoretical, economic, and operating factors encountered when free oxygen is added to the air and fuel used in developing heat in industrial furnaces. The enrichment of the

combustion air with oxygen is advantageous for two reasons: by accelerating the rate of combustion the fuel is burnt in a minimum volume, and by releasing the same amount of heat in the smaller volume the temperature is increased. Against these must be set the cost of enrichment, and the author shows how the advantages and disadvantages can be balanced so as to give an increase of efficiency without the cost being prohibitive.

Dry Blast.—*Silica Gel Air-Drying Process for Blast-Furnaces* (Iron and Coal Trades Review, July 24, 1925, vol. 111, pp. 129–130). Particulars are given of a system of drying air for blast by passing it through beds of silica gel.

Cleaning of Blast-Furnace Gas.—E. Davin, *Purifying Processes for Blast-Furnace Gas at the Plants of Heinrichshütte, Bochumer Verein, and G.B.A.G.* (Technique Moderne, 1925, vol. 17, p. 154).

Blast-Furnace Equipment.—C. E. Raeburn, *Vertical-Horizontal Blast-Furnace Charges* (Metropolitan-Vickers Gazette; Iron and Coal Trades Review, June 5, 1925, vol. 110, pp. 909–901). An illustrated description is given of a vertical-horizontal type of charger for blast-furnaces, including particulars of the electric control equipment.

F. W. Cramer, *The Automatic Blast-Furnace* (Iron and Steel Engineer, 1925, vol. 2, pp. 229–242). The author describes the working of the electric charging arrangement at the Johnstown plant of the Bethlehem Steel Corporation, which is operated by one man.

Manufacture of Ferro-Alloys.—A. J. Rossi, *Titanium and its Industrial Applications* (Revue de Métallurgie, Mémoires, Mar., Apr. 1925, vol. 22, pp. 121–138, 193–206). An account of the author's investigations in the metallurgy of titanium. In the blast-furnace the successful treatment of titanium iron ores would appear to depend on the proper selection of fluxes. The silicates of titanium are acid in nature and with suitable proportions of such bases as alumina, lime, and magnesia the slags obtained are fairly fluid. The use of dolomite is recommended, and by its means the titaniferous iron ores found in the Adirondacks have been successfully smelted in specially designed blast-furnaces. Such ores contain 10 to 12 per cent. of titanium oxide (TiO_2) and 55 to 56 per cent. of iron, and yield excellent pig iron containing traces only of titanium. Sometimes, however, a hard white pig iron containing up to 1 per cent. of titanium is produced. In the electric furnace, on the other hand, a wide range of ferro-titaniums can be produced. The higher the titanium, the higher the melting point of these products. Ferro-titanium containing 80 per cent. of titanium and over are now readily obtainable, but the carbon percentage is apt to be high, which constitutes a disadvantage. By

using aluminium in the bath it has, however, been found possible to get the carbon down to as low as 0.12, and although traces of aluminium are retained, they are too small to affect the result, particularly when used as an addition to steel.

A. J. Rossi, *Use of Titanium in the Iron and Steel Industry* (Iron and Coal Trades Review, May 29, 1925, vol. 110, p. 874). An abstract in English of the foregoing paper.

Recovery of Vanadium from Iron Ore.—R. von Seth, *Vanadium in Iron Ores and its Extraction* (Engineering and Mining Journal-Press, July 11, 1925, vol. 120, pp. 51–56). The author summarises the work of previous investigators on iron ore containing vanadium, and gives an account of the behaviour of vanadium in the blast-furnace and of the experiments hitherto made for the extraction of vanadium from iron ore. In the reduction of the ore in the blast-furnace practically the whole of the vanadium enters the pig iron. In the refining of pig iron the vanadium can be slagged off quickly and completely if the iron is not high in silicon and titanium. A decarburised steel retains little of the vanadium content of the pig iron. The author has devised a method for the extraction of vanadium in which basic pig is refined in an acid converter to form a slag rich in vanadium. This slag is poured off and the metal undergoes further refining in a basic converter to eliminate the phosphorus. The vanadiferous slag may be worked in the same way as the natural vanadium ores.

Electric Smelting of Iron Ore.—J. A. Leffler, *Electric Pig Iron Manufacture in Sweden* (Lecture before the Swedish Engineers' Society: Foundry Trade Journal, May 28, 1925, vol. 31, pp. 465–466). The author reviews electric furnace practice in Sweden for the manufacture of pig iron and gives brief particulars of the various plants in operation.

G. Tysland, *Electric Smelting of Iron Ore in Norway* (Tekn. Ukeblad., 1924, vol. 71, pp. 239–247, 251–256; Stahl und Eisen, Apr. 23, 1925, vol. 45, pp. 631–633). The author describes trials carried out at Fiskaa in Norway in the smelting of iron ore in low-shaft furnaces, using the Soderberg electrode. The energy consumption was from 2600 to 3500 kilowatt-hours per ton of iron produced, and the coke used, containing 85 per cent. fixed carbon, was 308 to 435 kilogrammes per ton. The trials were carried on for about twelve months, and a pig iron of good quality was regularly produced.

F. Giolitti, *Electro-Metallurgy of Iron and Steel in Italy* (Paper read before the World Power Conference: Iron and Steel of Canada, May 1925, vol. 8, pp. 103–106). In 1915 the Italian output of electric steel was 20,800 metric tons, and in 1922 it was 158,000 metric tons, while the number of electric furnaces increased from 12 to 178. The former figure represented only 2 per cent. of the total output and the latter more than 16 per cent. The author discusses the reasons for this great advance in the development of the electric steel industry in

Italy. The two main causes of this progress would seem to be a shortage of fuel and an abundance of water-power. The production of electric pig iron amounted to 62,000 tons in 1918, but subsequently the amount fell off very considerably. This production was nearly all so-called synthetic pig iron. However, the author thinks that this branch of the industry will revive again, in proof of which he describes the large establishment now in course of erection at the Ansaldo-Cogne Works at Aosta, where the whole process for converting the raw ore into high-grade steels will be carried out. Details are briefly given also of the electric manufacture of ferro-alloys.

H. Hermanns and S. Trincherò, *Works of the Cogne-Girod Company near Aosta* (Stahl und Eisen, June 4, 1925, vol. 45, pp. 891-892). An illustrated description is given of this new enterprise carried out under the direction of F. Giolitti and P. Girod. Four Héroult furnaces of 25 tons capacity and several smaller furnaces constitute the steelworks, and rolling-mills and accessory plant have also been installed. Five hydro-electric stations of a total of 100,000 horse-power supply 650 million kilowatt-hours to the works. The smelting furnaces are under the direction of the Ansaldo-Cogne Company and the steelworks under that of the Cogne Girod Company. The works have been built specially in order to exploit the ores of the Cogne mines 2500 metres above sea-level, the ores of which are a very pure magnetite with 55 to 68 per cent. iron. Special alloy steels are to be produced.

Electro-Metallurgical Development.—L. Le Chatelier and J. Cournot, *The Third Hydro-Electric Power Congress at Grenoble* (Revue de Métallurgie, Mémoires, Sept. 1925, vol. 22, pp. 545-567). Abstracts are given of the papers presented to the Grenoble conference. The paper by R. Blanchard consists of a review of recent progress in hydro-electric power developments in France with references to the electro-chemical production of iron, nickel, copper, aluminium, and magnesium. The hydro-electric power now employed in France is estimated at a million kilowatts; in other countries the following are the estimated figures: Norway, 850,000 kilowatts; Sweden, 650,000 kilowatts; Italy, 750,000 kilowatts; Switzerland, 650,000 kilowatts; and in the United States, 6 million kilowatts.

Mathieu and Sutler, *The Electro-Thermic Industry as to Pig Iron, Iron and Steel and Ferro-Alloys, and the Rational Use of Water Power in those Industries* (Revue de Métallurgie, Mémoires, Aug. 1925, vol. 22, pp. 477, 489). A report on the conditions of these industries and their prospects so far as France is concerned. Attention is drawn to the fact that electro-metallurgical operations are not always confined to regions and countries where cheap water power exists, nor even, in such countries as are endowed with such resources, to the districts where it is most developed. Electric furnace practice is commoner in the United States and in Germany than in France, the country of its invention. The direct production of iron from ore in electric furnaces is economical

only where rich ores abound. In France, owing to the cost of fuel, such a process is unsuitable. The manufacture of electric steel is carried out in more favourable conditions. Despite their excellent thermal efficiency and the fact that they do not consume electrodes, induction furnaces are, with the exception of the Röchling-Rodenhauser, not popular. Of arc furnaces, the Héroult is undoubtedly the most popular. With Soderberg electrodes they are likewise the most economical. The view is taken that, so far as French industry is concerned, the use of electric furnaces is at present confined to the production of high-grade steels and ferro-alloys. From that point of view every endeavour should be made to develop this industry, and the export of high-grade special steels and alloys to other countries. Some statistics of the existing trade are given, and directions indicated in which improved practice and methods may be adopted in order still further to develop it.

C. A. Keller, *The Electro-Metallurgical Works* (Arts et Métiers, July 1925, pp. 304–311). The article describes the characteristics of an electro-metallurgical works, and examples and illustrations are given from the works of Messrs. Keller and Leleux at Livet (Isère), France.

Iron Industries of Various Countries.—G. Bulle, *The Metallurgical-Technical Basis of the American Iron Industry* (Stahl und Eisen, July 2, 1925, vol. 45, pp. 1057–1067). Notes on the organisation and development of the American iron industry are given, with special reference to the mass production of materials of high quality.

H. Bleibtreu, *Organisation and Working of American Ironworks* (Stahl und Eisen, July 2, 1925, vol. 45, pp. 1067–1071). Some account of the management and control of ironworks is given. Personal touch between the managers and workmen inspires a keener interest in the work and leads to high efficiency and output.

H. Koppenberg, *Safety and Co-operation in the American Iron Industry* (Stahl und Eisen, July 2, 1925, vol. 45, pp. 1071–1075). The benefits arising from the safety movement in American ironworks are shown by statistics and by illustration.

H. Fromm, *Economic Conditions of Southern Manchuria, with Special Reference to the Iron and Coal Industry* (Stahl und Eisen, June 18, 1925, vol. 45, pp. 979–984). Developments in the coal-mining and iron-making industries in Manchuria are described. The principal coal mines are at Fushun, where a Koppers coke-oven plant, a large Mond gas plant, and electric power station have been erected; and at Anshan are iron ore mines and two blast-furnaces of modern design.

Pig Iron Prices.—J. W. Reichert, *Movement of Prices of the Principal German Iron and Steel Products from 1900 to 1924* (Stahl und Eisen, July 16, 1925, vol. 45, pp. 1242–1249). The average prices of pig iron and of all the chief rolled products are given for the period of twenty-five years from 1900, with lengthy considerations of the effect on the economic situation in Germany of the Versailles Treaty, the Ruhr,

occupation, the devaluation of the mark, and the compulsory free imports of iron and steel.

History of Iron.—O. Erlinghagen, *History of Iron Bridges from the Point of View of Structural Materials and Recent Developments in the Use of Steel of High Tensile Strength for Bridge Construction* (Kruppsche Monatshefte, May 1925, vol. 6, pp. 85–98). The first instance of the application of iron to bridge building is the well-known cast iron bridge at Coalbrookdale, built in 1776–79, which is still in use. Another example of an early cast iron bridge is one built in 1796 at Laasan in Germany. Following the development of the use of mild steel of a strength up to about 44 kilogrammes per square millimetre for bridge building, several instances are given of bridges constructed of nickel-chrome steel and of nickel steel with a tensile strength up to 65 to 70 kilogrammes per square millimetre. At present the tendency is in the direction of adopting carbon steel of about 0·4 per cent. carbon, and with silicon about 0·15, manganese 1·0, phosphorus not over 0·04, and sulphur not over 0·05 per cent., which with proper treatment will show a tensile strength up to 60 kilogrammes per square millimetre, the alloy steels having risen to a price when it is no longer economical to employ them on a large scale in structural work.

J. Newton Friend and W. E. Thorneycroft, *Ancient Iron from Richborough and Folkestone* (Paper read before the Iron and Steel Institute, Sept. 1925 : this Journal, pp. 225–232).

J. G. Butler, jun., *Early History of Iron and Steel Making in Mahoning Valley* (Iron Trade Review, Aug. 20, 27, 1925, vol. 77, pp. 425–428, 481–484). An account of the author's own experiences as one of the pioneers and founders of the industry in this district. These articles are taken from the author's book, "Recollections of Men and Events."

II.—BLAST-FURNACE SLAGS.

Utilisation of Slags.—G. Hartmann and others, *Granulation and Drying of Blast-Furnace Slag* (Stahl und Eisen, April 9, 1925, vol. 45, pp. 529–536). The various methods employed at five different iron-works for the granulation and drying of slag are described. At the Ilseder works a wet process is used, the slag being made to fall from a given height into a tank of water, from which it is removed by a chain and bucket elevator and discharged into the drier. There is no waste water, the feed to the tank being regulated so as to make up just the loss by evaporation. The steam containing sulphurous vapours is led off through a wooden trunk to prevent corrosion of the neighbouring iron structures by sulphur attack. The Borsig works has a wet system with a special form of drier, into which the slag sand, after passing through a water-tank, is lifted through a vertical rising

pipe by an air-blast at 28 inches pressure, taken from the blowing engines; the water is drained off in a revolving suction screen fitted with scrapers to prevent clogging, and the slag sand containing not more than 10 per cent. water is fed into the drier and discharged through traps in the bottom into cars. The Rolandshütte and Gelsenkirchener works both have special types of driers; and finally, the Buderus works have an arrangement for the granulation of slag by an air-blast into which a small stream of water is injected. This operation takes place in a revolving inclined drum, and the slag sand passing out at the lower end is removed by a bucket elevator to a hopper, from which it is loaded into the buckets of a ropeway.

Blast-Furnace Cement in the Rhineland (Tonindustrie Zeitung, 1925, vol. 49, pp. 996-998). The article describes methods of production of iron portland and blast-furnace slag cement, with a schedule of the producing works. The slag cement factory of the Vulcan works is illustrated and described.

R. R. F. Walton, *Notes on Blast-Furnace Slags* (Iron and Coal Trades Review, Aug. 28, 1925, vol. 111, p. 319). The author discusses the composition and function of blast-furnace slags.

E. T. Ellis, *Slag Wastes and their Utilisation* (Iron and Coal Trades Review, May 29, 1925, vol. 110, p. 875). A brief discussion of the utilisation of basic slag and blast-furnace slag.

III.—DIRECT PROCESSES.

Direct Production of Iron.—G. Hooghwinkel, *The Hornsey I.T. Process for Reducing Iron Ore* (Foundry Trade Journal, Sept. 10, 1925, vol. 32, pp. 215-216; Iron and Coal Trades Review, Aug. 28, 1925, vol. 111, p. 326). Particulars are given of the equipment used in the Hornsey process for the low-temperature reduction of iron ore, together with the results of experiments carried out on a commercial scale at the works of the Sheepbridge Coal and Iron Co., Ltd.

H. Flodin, *A New Direct Process* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 9-13).

FOUNDRY PRACTICE.

General Foundry Practice.—*Notes on Cupola Design* (Engineer, Aug. 7, 1925, vol. 140, pp. 144–146). Cupolas may vary from 24 inches to 90 inches diameter inside the lining, but a furnace 36 inches in diameter may be taken as representative, and the paper sets forth the deductions and improvements made on a cupola of this size.

The following dimensions will indicate the form finally evolved: The cupola is of the straight-line type; it has two rows of flared tuyeres, four large ones in the bottom row and two smaller ones in the top to complete the combustion of any escaping gaseous fuel. The ratio of combined tuyere area to cupola area was decided by experiment. The lower tuyeres were 26 inches above the sand bottom, allowing about 1 ton of metal to collect if required; the upper pair were 12 inches higher still (sketches are given to illustrate the general arrangement). The furnace melted between 4 and 4.5 tons of metal per hour, the iron coming out hot and fluid, and running very evenly throughout each heat. A small fuel saving was also effected. The air required was 2500 cubic feet per minute. The author indicates clearly the direction in which alterations would be necessary in applying his results to larger furnaces.

L. Franz, *Practical Results Obtained with the Schürmann Cupola* (Giesserei Zeitung, May 15, 1925, vol. 22, pp. 277–282). Structural details are shown of the Schürmann cupola and of the chambers for preheating the blast, and data of the working over a period of three months are given. The saving in coke, compared with the ordinary cupola, appears to amount to about 25 to 27 kilogrammes per ton of metal, and, using the same mixtures, the product of the Schürmann cupola contains sulphur 0.077 to 0.09 per cent. as compared with 0.12 per cent. sulphur in the product of the ordinary cupola. Measurements showed that the average temperature of the blast was 985° C. The refractory lining burns away rather more rapidly than in an ordinary cupola.

K. Emmel, *Low Carbon Cast Iron as a Product of the Cupola* (Stahl und Eisen, Aug. 27, 1925, vol. 45, pp. 1466–1467). Though the strength properties and density of a cast iron having a total carbon of 3.2 per cent. may be excellent, yet an iron with carbon 2.5 to 2.8 per cent. may give much better results. In such an iron not only is the proportion of graphite lower, but it is in a much more finely divided condition. Tables show that in cast iron with total carbon ranging from 2.39 to 2.84 per cent. the tensile strength is from 30 to 41 kilogrammes

per square millimetre. The iron is made in the cupola according to a new process devised by Thyssen and Emmel, details of which are not yet given. The results of bend tests are also given, showing a bending strength of 60 to 74 kilogrammes per square millimetre, with bars 15 and 30 millimetres diameter machined and plain.

K. Emmel, *Low Carbon Cast Iron Produced in Cupolas* (Foundry Trade Journal, Sept. 24, 1925, vol. 32, pp. 255-259). An English translation of the foregoing paper in Stahl und Eisen.

H. Hermanns, *The Thyssen-Emmel Process* (Foundry Trade Journal, Aug. 6, 1925, vol. 32, pp. 113-114). A lengthy abstract in English of an article appearing in Giesserei Zeitung, describing the properties of a cast iron produced by the Thyssen-Emmel process. The iron has a perfectly homogeneous structure in all wall thicknesses and can be produced in the ordinary cupola; although no particulars of the process are included in the paper. Tensile and transverse tests of this iron have been carried out at the Yorkshire Testing Works and the results are tabulated.

T. Klingenstein, *A New Furnace of the Wüst Type, for the Improvement of High Quality Cast Iron* (Stahl und Eisen, Aug. 27, 1925, vol. 45, pp. 1476-1478). It is beyond doubt that a pearlitic grain in cast iron, owing to its eutectic structure, imparts properties which render it superior to any other ferritic cast iron. A method of operation is described in detail by which the carbon is kept down to 3 per cent. or slightly less, giving particulars of the mixtures used, their composition, the composition of the castings, and the results of mechanical tests. An oil-fired flame furnace is used, sectional drawings of which are shown, and the figures of oil consumption are stated.

E. Piwowarsky and F. Meyer, *The Economic Adjustment of the Cupola* (Stahl und Eisen, June 25, 1925, vol. 45, pp. 1017-1022). On the basis of trials on a large scale the authors have endeavoured to determine the relation between air supply and coke consumption in the cupola. They find that it is quite within the bounds of possibility to adjust a cupola to the optimum degree of thermal efficiency without affecting output and temperature of the iron. The consequences of an excess of coke are more serious than a moderate excess or a slight under-supply of air. The coke charge may be lowered to about 7 per cent. without affecting the loss of iron by burning.

E. Piwowarsky and F. Meyer, *The Adjustment of Cupola Furnaces from the Point of View of Heat Economy* (Foundry Trade Journal, Aug. 13, 1925, vol. 32, pp. 133-137). An English translation of the foregoing paper in Stahl und Eisen.

J. Grennan, *Cupola Melting Rate as Affected by Tuyere Ratios* (Paper read before the American Foundrymen's Association, Oct. 1925). A number of experimental heats were run in order to determine if any changes in the rate of cupola melting occurred with alteration in the size of tuyeres. The results indicate that the size of tuyeres has little effect on cupola melting. An ideal set of tuyeres is one in which there

is a minimum amount of friction offered to the blast and one which distributes the air uniformly around the cupola. The continuous tuyere of a 1 to 4 ratio satisfies these requirements.

A. Wagner, *Desulphurisation and Reduction in the Cupola* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1205-1207). A study is made of the comparative value of different manganiferous additions as desulphurisers in the cupola. Reusch obtained excellent results with clay schist containing 38.48 per cent. MnO, with which he succeeded in removing not only the sulphur of the coke but also the pig iron sulphur. Wüst used manganese ore with 91 per cent. MnO₂ but with less success, his product averaging 0.064 per cent. sulphur. Wedemeyer tried manganese ore with 70.62 per cent. Mn₃O₄, but could only bind the coke sulphur, the pig iron sulphur being quite unaffected. The author has made trials with ferro-manganese slag containing 18.46 per cent. MnO; this also contained 1.11 per cent. sulphur, but analysis showed that this did not pass either into the metal or the slag, and it was concluded that it became oxidised in the gas, passing off in the form of sulphur dioxide. The desulphurising effect of ferro-manganese slag proved to be only moderate, the proportion of sulphur removed varying from 18 to 36 per cent. Such an addition, however, prevents the iron from taking up sulphur from the gases, and in the case of a high sulphur content of the charge it exercises a stronger desulphurising effect than limestone. An equally good effect can be obtained with fluorspar.

E. Diepschlag, *Methods of Improving the Quality of Grey Iron Castings* (Giesserei Zeitung, Sept. 1, 1925, vol. 22, pp. 519-527). Consideration is given to the influence of various elements on the properties of cast iron. The effects of silicon and of manganese on the formation of graphite are clearly shown by means of diagrams, together with the effect of increasing percentages of carbon. Other diagrams show the influence of carbon, silicon, manganese, and phosphorus on the mechanical properties. The strength of grey iron castings is increased by lowering the carbon and correspondingly raising the silicon, in conjunction with a suitable heat treatment. A general discussion on the paper took place.

E. Diepschlag, *Methods and Aims of Grey Cast Iron Refining* (Paper read before the German Foundrymen's Association: Foundry Trade Journal, July 30, 1925, vol. 32, p. 100).

E. Piwowarsky, *Influence of Temperature on the Graphite Formation in Pig and Cast Iron* (Stahl und Eisen, Aug. 27, 1925, vol. 45, pp. 1455-1460). Certain investigators have shown that with increasing casting temperature there is a distinct decrease in the percentage of graphite in the casting. Others again have noted an increase in graphite with rising casting temperatures. In previous experiments, however, the highest temperature used was not above 1425° C., and the author therefore, considering that the use of a wider temperature range would throw more light on the matter, has made trials with casting temperatures up to 1800° C., and a Swedish white iron containing carbon 4.01 and silicon

0.13 per cent. was used for the melts, which were heated, one in a carbon crucible and two in magnesia crucibles in an electric furnace, each melt weighing 50 grammes. The last two series were melted in an atmosphere of nitrogen. All the melts were allowed to cool at the rate of 3° per minute until 20° or 30° below the eutectic arrest point, and were then plunged in water while still in the crucible. The results, plotted in curves, show that the eutectic carbide carbon content increases as the temperature rises to about 1500° . But heating beyond 1500° and up to 1800° favours the formation of eutectic graphite. The experiments were repeated with iron containing 2.4 per cent. silicon (siliconised by the addition of high grade ferro-silicon) and the results were much the same except that the point at which the tendency to form graphite rather than carbide carbon was 1400° . Every kind of liquid pig or cast iron has a distinctive temperature range dependent upon its composition, above which the iron increasingly tends to solidify as grey. The results appear to justify the assumption of the coexistence of two types of molecules in the liquid condition, to which may be attributed a graphite-promoting or carbide-promoting effect according to the type of molecule which predominates.

E. Piwowarsky, *The Influence of the Temperature upon the Formation of Graphite in Pig and Cast Iron* (Foundry Trade Journal, Oct. 15, 1925, vol. 32, pp. 317-320). An English translation of the foregoing paper.

H. J. Young, *A Description of the Perlit Process* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Oct. 8, 1925, vol. 32, pp. 294-295). Some of the advantages of the Perlit process for the production of iron castings are pointed out.

H. W. Dietert and W. M. Myler, jun., *Continuous Iron Temperature Recording* (Paper read before the American Foundrymen's Association, Oct. 1925). The paper describes a continuous temperature-recording instrument for cupolas, its method of application and the results obtained. A thermocouple with a protecting hood is attached to the cupola spout for measuring the temperature of the gases given off by the molten iron, which bears a definite relationship to the iron temperature. The object of the hood is to form a support for the thermocouple and also to collect the gases without the intermingling of air. The recording mechanism indicates the temperature of the iron at any period of the melt, and also makes a continuous record of the temperature throughout the heat.

H. Esselbach, *The Use of Scrap in the Cupola* (Giesserei Zeitung, July 15, 1925, vol. 22, pp. 432-435). The kinds of scrap cast iron and scrap steel suitable for use in the cupola are enumerated, and the maximum limit is stated of the elements which the scrap can suitably contain. Reasons for not using too high a proportion of scrap in making up the charge are given, though with care it is possible to produce a satisfactory cast iron with a charge made of 100 per cent. scrap.

Melting of Steel Pieces in the Cupola (Giesserei Zeitung, Aug. 15,

1925, vol. 45, pp. 486-490). Experiments in a cupola show that the melting of steel pieces, when added to the charge, proceeds exactly in the same manner as when melted by any other process. Pieces of steel over $1\frac{1}{2}$ inch thick should best be charged direct on to the coke bed. Steel pieces of less thickness can be charged on top of the pig iron, and they will melt quite as rapidly as the pig.

R. Lehmann, *The Production of Castings, with Special Reference to Iron Castings* (Die Giesserei; Foundry Trade Journal, July 9, 16, 1925, vol. 32, pp. 35-38, 53-54). The author outlines principles for the correct construction of castings in relation to material, moulding, casting, and cleaning.

Losses Incurred in Melting Iron (Foundry Trade Journal, July 16, 1925, vol. 32, p. 58). The chief factors determining the losses incurred in cupola practice are briefly discussed.

S. J. Felton, *Superheating Iron in the Cupola* (Paper read before the American Foundrymen's Association, Oct. 1925). The author discusses the relative effects of oxidation, differences between melting and freezing points of cast iron, and heat absorption by conduction, radiation, and convection, on the temperature of cupola iron.

German Foundrymen's Association (Foundry Trade Journal, July 16, 1925, vol. 32, pp. 61-62). A report of the meeting of the German Foundrymen's Association held in Munich in June 1925. Brief abstracts are included of the following four papers:

Zerzog, *The Valuation and Testing of Foundry Coke*.

Klingenstein, *Desulphurisation in Cupolas, with Special Reference to Fluorspar*.

Behr, *The Structure of Clays for Cupola Furnaces*.

W. Claus, *Deoxidation Processes and Deoxidising Agents for Non-Ferrous Metal Meltings*.

T. Klingenstein, *Fluorspar and Slag Formation in the Cupola* (Giesserei Zeitung, June 1, 1925, vol. 22, pp. 311-316). Cupola slags in the ordinary way consist of silica and lime, the lime being added. It has been urged by some that fluorspar has a stronger desulphurising effect than other alkaline salts, but trials show definitely that this is not the case, and that of all the desulphurising agents which may be used in the cupola fluorspar is the least effective. Its use would therefore only be justified if for any reason a suitable limestone were unobtainable.

The Practical Value of Cupola Slags (Metal Industry, Oct. 9, 1925, vol. 27, pp. 341-342). Such details as colour and weight of slags formed and the presence of "iron shot" and foaming can be made to yield valuable information on the processes going on within the cupola. The author describes and explains some of the tell-tale signs.

H. Larsen, *The Durability of Cupola Linings* (Giesserei Zeitung, May 15, 1925, vol. 22, pp. 283-288). A discussion of the chemical, physical, and mechanical conditions which affect the life of the refractory linings of cupolas.

S. Leeb, *Cupola Linings* (Giesserei Zeitung, July 15, 1925, vol. 22, pp. 422-431). The various methods of lining cupolas are discussed, and the characters of the various materials used for the purpose are considered. The cheapest and most efficient lining appears to be the rammed lining put in with a compressed air stamping machine.

The Improved Hurst Oil-Fired Receiver (Foundry Trade Journal, Aug. 13, 1925, vol. 32, pp. 146-147). Particulars are given of the improvements recently introduced in the design of the Hurst oil-fired receiver for cupolas.

G. E. Lamb, *The Electric Melting of Cast Iron* (Paper read before the American Foundrymen's Association, Oct. 1925). The author describes his experiences in the melting of cast iron in an acid electric furnace. Troubles encountered in melting alternate heats of iron and steel are also discussed.

G. S. Schaller, *Synthetic Cast Iron and its Possibilities for the Seattle District* (Paper read before the American Foundrymen's Association, Oct. 1925). A discussion of the factors entering into the production of synthetic cast iron and the application of the process to the Seattle district.

H. C. BeMent, *Making Low Cost Iron Castings from Iron Borings* (Iron Trade Review, Sept. 10, 1925, vol. 77, pp. 626-627). The melting of iron borings in an electric furnace for the production of castings is described. Particulars are given of the power required and the cost per ton of castings.

The Casting-in of Lubricator and Similar Tubes (Metal Industry, July 31, 1925, vol. 27, pp. 99-100). The article describes a method of casting-in small iron or steel tubes whereby passages of curved contours can be provided and expensive machining operations avoided.

J. H. List, *What Constitutes a Waster Casting* (Metal Industry, July 24, 1925, vol. 27, pp. 81-82). The author is of opinion that there is no definite line of demarcation between good castings and wasters. A great deal depends, in the case of smaller defects, on the position of the fault in relation to the casting as a whole, and another point that should be considered is the use to which the casting will be put. Many defects of a minor character can be rectified, and so save the expense involved in rejecting the whole casting.

J. H. List, *Cold-Laps in Cast Iron* (Iron and Steel of Canada, June 1925, vol. 8, p. 123). A brief description of some of the causes of cold-lap in cast iron.

S. G. Smith, *Castings which give Trouble under Pressure Test* (Foundry Trade Journal, Sept. 3, 1925, vol. 32, pp. 204-206). A discussion of the points to be observed in the moulding, pouring, and feeding of castings for steam-turbine cylinders.

L. Zerzog, *Foundry Coke* (Giesserei Zeitung, Aug. 15, Sept. 1, 1925, vol. 22, pp. 477-485, 528-539). A general study of the characteristics, composition, and properties which a good foundry coke should possess.

Foundry Mixtures.—*The Use and Abuse of Hæmatite Pig Iron* (Metal Industry, June 26, 1925, vol. 26, pp. 633–635). It is stated that the practice of making an addition of a proportion of hæmatite iron to foundry mixtures in order to produce strong, close-grained irons is based on a fallacy, and that the best that can be said for it is that the phosphorus will be diluted. The initial condition of the graphite in the hæmatite pig has a marked effect on the arrangement and condition of the free carbon in the casting; during remelting with the mixture the graphite of the hæmatite iron is apparently not completely reabsorbed and forms nuclei in the solidifying metal which grow by graphitisation during the cooling of the casting, giving a weak, open-grained iron. If the phosphorus of a mixture must be reduced, a hæmatite iron should be chosen with not more than 3·5 per cent. total carbon, the graphitic portion of which should be in small particles and easily soluble. It might even be advantageous to melt the hæmatite iron separately so as to refine it somewhat.

R. Hopfelt, *Boiler Furnace Bars* (Zeitschrift des Vereines Deutscher Ingenieure, Mar. 28, 1925, vol. 69, pp. 411–414). Experiments were made to determine the effect of variation of composition of white and grey cast iron fire-bars on their resistance to the action of heat. Hard white iron need not necessarily be used, but the phosphorus and sulphur should be as low as possible. By adding aluminium in small quantities to the iron, cleaner castings of finer structure are produced without appreciably affecting the resistance to the action of fire. For thin bars a higher aluminium addition is justified, and such bars tend to give better combustion, and consequently lead to economy in coal.

B. Szöke, *Calculating Cupola Mixtures* (Iron Age, July 23, 1925, vol. 116, pp. 205–207, 258). The graphic solution of problems of calculating cupola mixtures is discussed, and an apparatus is described for rapid calculation.

Steel Foundry Practice.—A. W. Gregg and N. R. Knox, *Notes on the Operation of a 1½-Ton Electric Furnace Producing a Large Tonnage* (Paper read before the American Foundrymen's Association, Oct. 1925). The authors record the performance of a basic electric furnace. The furnace has a rated capacity of 1½ ton, but charges ranging from 2500 lbs. to 7000 lbs. have been run. When pushing the furnace to the limit a charge of 6200 lbs. was found to give a maximum tonnage with greatest ease of operation. Ten heats of 6200 lbs. can be obtained within twenty-four hours. A log of an average heat is given, with a discussion of furnace operations. Tables giving particulars of costs of all items of operation and results of tests on the steel produced are included.

S. R. Robinson, *Carbon Steel and Carbon-Vanadium Steel by the Converter Process* (Paper read before the American Foundrymen's Association, Oct. 1925). The author describes converter practice at the Industrial Works, Bay City, Michigan, for the production of steel

castings. For carbon steel the cupola charge consists of 70 per cent. steel scrap and 30 per cent. low phosphorus pig iron. Refining is carried out in a 3-ton side-blown converter. Soda ash is added in the ladle to the cupola metal as a desulphuriser. Ferro-manganese is added in the converter, and ferro-silicon in the ladle. Very little manganese is used. The analysis of carbon steel is kept within the following limits : Carbon, 0.17 to 0.22 ; manganese, 0.75 to 1.00 ; silicon, 0.30 to 0.40 ; phosphorus, under 0.05 ; sulphur, under 0.07 per cent. The cupola charge for vanadium steel consists of low phosphorus pig and steel scrap in equal quantities. The cupola metal is treated with soda ash, ferro-manganese is added in the converter, and ferro-vanadium and ferro-silicon in the ladle. Analysis is kept within the following limits : Carbon, 0.35 to 0.40 ; manganese, 1.00 to 1.10 ; phosphorus and sulphur, below 0.05 ; silicon, 0.30 to 0.40 per cent. ; and vanadium, 0.18 per cent. The heat treatments for both types of castings are given.

F. E. Hinners, *Electric Furnace replaces Converter* (Electric World, 1925, vol. 86, p. 374). Experiments with a 3-ton electric furnace show that the castings produced are equal, if not superior, to those produced in the converter. The advantages of the electric furnace are enumerated.

Electric Furnace for Foundry (Iron Trade Review, July 9, 1925, vol. 77, pp. 69, 105). Brief particulars are given of a direct-arc type of electric furnace installed in an American steel foundry. The electrode holder is air-cooled. The furnace has a capacity of $1\frac{1}{2}$ ton, and the average power consumption on steel heats is 625 kilowatt-hours per ton.

G. L. Lacher, *Steel Foundry Capacity Doubled* (Iron Age, Oct. 8, 1925, vol. 116, pp. 947-951). The lay-out of the new foundry of the Bucyrus Co., South Milwaukee, is described and illustrated. Both electric furnaces and basic open-hearth furnaces are in operation.

Manufacture of Steel Castings in India (Foundry Trade Journal, July 30, 1925, vol. 32, pp. 93-95). The equipment of the Hukumchand Electric Steelworks in Calcutta is described and illustrated. Two 30-cwt. Stobie furnaces are in operation for the production of steel castings for railway rolling stock and general engineering purposes.

K. von Kerpely, *Manufacture of Manganese Steel Castings in the Electric Furnace* (Giesserei Zeitung, Aug. 1, 1925, vol. 22, pp. 445-449). The author describes fully the metallurgical operation involved in the production of manganese steel castings containing 12 to 13 per cent. manganese. Full particulars are given of the materials charged, of the additions and the intervals at which they are added, the nature of the slag, and the current consumption. The moulds are made either from green or dry sand. For small castings quartz sand is used, and for larger ones magnesite prepared from sintered magnesite or by grinding up old magnesite bricks, with raw clay as a binder. A good mixture is 8 to 9 parts of magnesite and 1 to 2 parts clay. A fireclay graphite mixture consisting of 20 parts of best burnt

fireclay, 8 parts raw clay, 4 parts best graphite, 3 parts of ground coke, and 2 parts of silversand has also given very good results. The castings are allowed to cool down in the mould, and after cleaning are heated very slowly to 1050° to 1100° C. and quenched suddenly in cold water, of which there must be an ample quantity so that it should not rise above 15° C.

J. H. Hall, *High Manganese Steel Castings* (Iron Age, Oct. 1, 1925, vol. 116, pp. 879-884). The author summarises the results of over 1800 tests of manganese and other steel castings. In recent years the 1.25 per cent. manganese steel has found favour among steel users and is now being tried in the shape of forgings and rails and in other forms besides castings.

D. F. Ducey, *Making Miscellaneous Steel Castings for Navy Use* (Paper read before the American Foundrymen's Association, Oct. 1925). An account of foundry practice at the Puget Sound Navy Yard for the supply of steel castings for the United States Navy.

S. H. Bunnell, *Makes Steel from Unselected Scrap* (Iron Trade Review, Sept. 3, 1925, vol. 77, p. 559). Brief particulars are given of the design of the Bosshardt open-hearth furnace for the production of steel castings.

R. Krieger, *Standardisation of Steel Castings* (Stahl und Eisen, May 28, 1925, vol. 45, pp. 837-839). The terms of a specification for steel castings are published, and the author, as chairman of the sub-committee for standardisation of steel castings, discusses the conditions and compares them with those of American specifications.

Chilled Castings.—P. Goerens and H. Jungbluth, *Chilled Castings* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1110-1117). After reviewing the principal literature on the subject of chilled castings the authors describe experiments made with the object of determining the influence of the carbon, silicon, and casting temperature on the depth of chill. The influence of carbon is clearly shown on the curve, the hardness rising from 200 to 500 Brinell as the carbon rises from 1 to 4 per cent. The dependence of the depth of hardening on the percentage of silicon is also shown by curves, and the curves of Schüz, Adamson, and Goerens and Jungbluth, showing the increase in the depth of chill as the silicon decreases, are combined to form an ideal curve for the influence of silicon.

The Manufacture of Chilled Castings (Foundry Trade Journal, May 28, 1925, vol. 31, pp. 456-457). The defects encountered in the production of chilled castings are briefly discussed.

A. Allison, *Experiments in the Manufacture of Chilled Iron Rolls* (Foundry Trade Journal, June 4, 1925, vol. 31, pp. 481-483; July 9, 1925, vol. 32, pp. 27-30). The author gives the results of experiments on the production of chilled iron rolls. Silicon is the determining element in respect to chill, and nearly all the experiments showed that the chill varied inversely with the silicon. Manganese in excess of 0.3 per

cent. seriously affects the depth of chill. The total carbon should not exceed 3.3 per cent. for satisfactory service. The temperature range for casting is very small, approximately 1210° to 1250° C.

R. A. R. Cole, *The Manufacture of Chilled Iron Rolls* (Proceedings of the Institution of Mechanical Engineers, 1925, No. 1, pp. 93-98). A general outline is given of the process of the manufacture of chilled iron rolls.

P. Dwyer, *Holds Uniform Temperature in Permanent Moulds of New Type* (Iron Trade Review, Oct. 8, 1925, vol. 77, pp. 887-891). The author gives particulars of a new type of permanent mould, which is oil-cooled to overcome fluctuations and uneven distribution of the temperature of the mould.

Making Castings Continuously in Permanent Moulds (Iron Trade Review, May 21, 1925, vol. 76, pp. 1325-1328). A description is given of a system of casting in permanent moulds. Continuous pouring is carried out on a casting table holding fifteen moulds. Chilling is prevented by heating the cast iron moulds before use for twelve hours in powdered zinc at a temperature of about 900°. A small quantity of the zinc taken up by the mould is gasified by the temperature of the casting, thus forming a thin film of gas between the cast metal and the mould. By decreasing the thickness of the mould, chills may be produced where desired.

L. Frommer, *Die-Casting and its Place in the Technology of Metals* (Zeitschrift für Metallkunde, Aug., Sept. 1925, vol. 17, pp. 245-250, 289-293). Practice in die-casting is illustrated and described, and its applicability to the production in large quantities of precisely similar small castings is emphasised.

Moulding Sands.—A. L. Curtis, *Steel Moulding Sands and their Behaviour under High Temperatures* (Iron and Steel Institute, Carnegie Scholarship Memoirs, 1925, vol. 14, pp. 1-89). The author shows that very great variation occurs in natural argillaceous sands of Pliocene origin, of which the St. Erth (Cornwall) variety is taken as being thoroughly representative. Similar variations occur in steel-facing mixtures in current practice. It is desirable, therefore, that control tests should be much more frequently carried out before either choosing supplies of raw sands or preparing facing mixtures in the steel foundry. It is shown that variation in quality of natural sands can be more quickly proved by refractory and washing tests than by chemical analysis. These methods would, therefore, be suitable for control tests. A complete series of samples of Cornish sands were tested for permeability and crushing strengths. A method is also described for photographing samples of sands and other minerals during exposure to varying degrees of heat, up to the temperature of complete fusion, the samples being placed in rectangular fireclay troughs, and fused with an oxygen gas blowpipe. A large number of photomicrographs of sands taken at temperatures ranging from 1200° to 1790° C. are shown.

C. Irresberger, *Methods for the Investigation of Moulding Sands and of their Preparation for Use* (Stahl und Eisen, Aug. 27, 1925, vol. 45, pp. 1481-1485). The author reviews the work of the Committee of the American Foundrymen's Association appointed to study the question of properties and treatment of moulding sands, the reports of which have been published by that Association. These described methods for determining the three important properties of sands—namely, permeability, strength of cohesion, and grain-size—and a summary of these methods is given, with illustrations of the apparatus employed.

E. Diepschlag and H. Pannek, *The Relations of Grain-Size and Shape to the Permeability of Moulding Sand* (Stahl und Eisen, Apr. 30, 1925, vol. 45, pp. 649-653). The results of experiments show that any relation between permeability and grain-size of moulding sand must depend on the form of the minerals contained in the fractions. By means of a Treuheit-Gessers washing apparatus three fractions were obtained from a moulding sand, and the grain-size of each fraction was determined. In general, it was found that moulding sands may be divided into two groups. Group 1 consists of sands whose second and third fractions (that is, the finer ones) contain more than 10 per cent. of conglomerates of a sharp-edged form. If the coarse grains of the first fraction be added to these, the permeability falls until 45 per cent. of the first fraction is reached. Thereafter the permeability rises rapidly. The second group consists of sands whose finer constituents are quartz and silicate grains approximating to spherical form. This group is divided into two subdivisions: (a) containing over 20 per cent. of coarse grain, and (b) containing less than 20 per cent. of coarse grain. In these two subdivisions the permeability increased as the proportion of coarse grain was increased, but (b) also showed an increase in permeability when the proportion of grains of the finest size was reduced.

H. W. Dietert, *Apply Test Methods to Aid in Controlling Sands in Foundries* (Foundry, May 1, 1925, vol. 53, pp. 361-366). A comprehensive account of the procedure for the testing of moulding sands used in the laboratory of the United States Radiator Corporation, Detroit.

R. F. Harrington, W. L. MacComb, and A. Hosmer, *Heat affects Clay Content in Moulding Sands* (Foundry, 1925, vol. 53, pp. 221-222, 248). The utility of a moulding sand depends upon the development of the colloidal content in the green clay, also upon the extent to which this property is destroyed under various conditions of heat. Clays obtained from gravels from the same geological formation and mined from the same district were subjected to varying degrees of temperature and then tested. The decrease in colloidal content was fairly uniform up to 538°. Above this temperature the colloidal content and dye adsorption values were not similar. The results show that relative bonding properties vary widely in sands used for moulding.

H. Ries, *The Present Status of the Laboratory Investigation of Sands*

(Paper read before the Institute of British Foundrymen : Foundry Trade Journal, June 11, 18, 1925, vol. 31, pp. 495-497, 523-525). The author reviews the work carried out in the United States on the testing of moulding sands. The various methods of testing are briefly described.

A. A. Grubb, *Selection and Blending of Core Sands* (Paper read before the American Foundrymen's Association, Oct. 1925). The author outlines principles and methods for the selection of core sands and for the compounding of core-sand mixtures for various purposes. By proper selection of sand with regard to grain-size and clay content great economies can be effected.

J. F. Harper and W. J. Stevenson, *Methods of Testing Core Sand Mixtures* (Paper read before the American Foundrymen's Association, Oct. 1925).

H. W. Dietert and W. M. Myler, jun., *Moulding Sand Control in the Foundry* (Paper read before the American Foundrymen's Association, Oct. 1925).

F. C. Edwards, *Extending the Uses of the Oil-Sand Core* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, May 21, 1925, vol. 31, pp. 429-432). The author enumerates some of the advantages obtained by the use of oil-sand cores in foundry work.

F. C. Edwards, *Making Oil-Sand Cores* (Metal Industry, July 3, 1925, vol. 27, pp. 7-9). The types of sands to be used, the nature of the bond, the oils used, methods of mixing the sands and oils, and the process of making the cores and drying them are all described. The effect of grain-size on venting capacity is also indicated.

M. Sklovsky, *A Method of Treating and Handling of Moulding Sand* (Paper read before the American Foundrymen's Association, Oct. 1925). The author describes a method and apparatus used in handling moulding sand. A special revolving shelved apparatus is used to cool, aerate, and cut the sand so that the sand passes through a complete cycle every thirty minutes.

Foundry Sand Recovery Plant (Engineer, May 22, 1925, vol. 139, p. 572). The plant, which is shown in a photograph, sorts out any pieces of iron by a magnetic separator and then screens the remaining sand in a $\frac{1}{4}$ -inch mesh expanded metal sieve. The fines from this are fit to return to the foundry for use again. The whole plant is driven by one D.C. motor, and a special switch is provided which starts the motor and magnetic separator together. An automatic device on the switch allows the magnetic separator to receive a momentary heavy current in excess of the normal, in order to obtain the highest possible flux density in the magnet ; when the current drops, this high flux density is of course maintained by the "retentivity" of the iron forming the magnets.

Handling Sand to Speed Output (Foundry, May 15, 1925, vol. 53, pp. 412-415). An illustrated account of the system for the preparation and distribution of sand at an American foundry.

Moulding.—P. Dwyer, *Special Moulding Machines* (Foundry, May 1, 1925, vol. 53, pp. 345–348). An illustrated description of the methods and moulding machines in use in a Canadian foundry for the production of castings for agricultural machinery.

P. Dwyer, *Machines supplant Hand-Moulding Methods* (Iron Trade Review, Aug. 15, 1925, vol. 53, pp. 647–650). Machine moulding practice at the plant of the Richardson and Boynton Co., Dover, New Jersey, is described and illustrated.

L. Schmid, *A New Process for the Manufacture of Pattern Plates* (Giesserei Zeitung, 1925, vol. 22, pp. 365–368). The author describes the moulding and casting of pattern plates and the alloys of which they are compounded. After casting, the surfaces of the plates are machined and carefully polished and are tested as to their mechanical and physical properties.

A. Haug, *The Pattern Plate* (Stahl und Eisen, July 30, 1925, vol. 45, pp. 1301–1306). The advantages of the use of iron or bronze pattern plates are discussed, especially from the point of view of mass production of precisely similar castings. Cast iron plates are generally used for castings of fairly large dimensions and having thin walls, such as hollow-ware. For small patterns other metals are more suitable, such as brass, bronze, or aluminium alloys, for the reason that these materials are lighter and easier to cast and machine, with the further advantage that they do not rust.

A. Haug, *Pattern Plates* (Foundry Trade Journal, Aug. 20, 1925, vol. 32, pp. 163–166). An English translation of the foregoing paper on the use and types of pattern plates.

H. A. Russell, *Correct Malleable Casting Patterns* (Iron Age, May 7, 1925, vol. 115, pp. 1331–1334). The author discusses some of the common errors occurring in the design and gating of patterns for malleable castings.

Making Castings for Waterworks (Foundry, May 1, 1925, vol. 53, pp. 350–355). Moulding practice for the production of valves, hydrants, and other fittings for water supply is described and illustrated.

Moulding a Special Pipe (Metal Industry, July 10, 1925, vol. 27, pp. 33–34). A method of moulding special pipe castings is described, in which the core is loamed to give the pattern.

F. C. Edwards, *Moulding a 20-Foot Girder in Greensand* (Metal Industry, June 12, 1925, vol. 26, pp. 583–585). The author describes a method of greensand moulding that was adopted for casting a grey-iron girder, 20 feet long, 2 feet 6 inches deep, and weighing 5 tons. A saving of expenses of 25 per cent. was made over the ordinary method of using dry sand moulds, which would have needed a very large stove capacity.

H. A. Hart, *Makes Large Condenser Shell* (Foundry, Aug. 1, 1925, vol. 53, pp. 601–605). An illustrated account is given of the methods employed at the River Rouge plant of the Ford Company for making the moulds for castings for steam turbo-generators.

J. W. Bolton, *Metallurgy of Iron Dryer Rolls* (Iron Age, Sept. 24, 1925, vol. 116, pp. 800-802). The author discusses the mechanical and chemical problems involved in the production of seamless iron dryer rolls for use in paper mill machinery. The rolls are steam-heated and used in batteries of as many as ninety in paper machines. The castings, which are hollow, are produced up to 60 inches in diameter and 15 feet long, with $1\frac{3}{8}$ inch thickness of shell. The rolls are cast with seamless heads with journals cast on. The castings are poured end-on and a collapsible core is used, being removed through a small manhole through the head of the casting.

E. Longden, *Importance of Venting, with Special Reference to Defective Castings* (Foundry Trade Journal, May 28, June 4, 1925, vol. 31, pp. 449-452, 471-474). The author discusses the effect of gases, especially those given off from the mould during pouring, on the soundness of grey iron castings. The practice of venting greensand, dry sand, and loam is dealt with.

Some Studies in Mould Handling (Iron Age, July 30, 1925, vol. 116, pp. 272-274). Illustrated particulars are given of the use of a portable mould table at an American Foundry.

Mould and Core Drying Stoves (Engineering, Sept. 18, 1925, vol. 120, p. 372). A brief description and plans are given of the stoves built by Messrs. August's Muffle Furnaces, Ltd., Halifax, for mould and core drying purposes.

Self-contained Heater for Foundry and Metallurgical Use (Engineering, June 5, 1925, vol. 119, pp. 700-701). Oehm's patent heating element is described. It consists of two compartments; in the first, fuel is burned, the air passing up the fire-bars in the usual way. The draught is induced by an air-jet working at 70-80 lbs. pressure injecting into the second compartment of louvred bricks, which, forming one side of the first compartment, are already hot. The air-blast is also preheated by passing through pipes contained in the "other" wall of the second compartment, with the effect that the gases from the first chamber, in which the carbon is mostly present as CO, are completely burnt to CO₂ and issue from the exit orifice at about 2550°-2800° F. These gases are then led to whatever requires to be heated. The furnace is said to give excellent results when drying moulds, heating ladles, &c., and is adaptable to other work.

Centrifugal Casting.—P. Doat, *A New Process for the Manufacture of Cast Iron Pipes* (Revue Universelle des Mines, June 15, 1925, vol. 6, pp. 306-312). The author describes the De Lavaud machine for making centrifugally cast pipes. The metal is cast in a horizontal revolving water-cooled mould and soon cools sufficiently to be withdrawn, but requires heat treatment, for the outer surface is excessively hard owing to the chill effect of the water-cooled mould. The paper includes micrographs of sections of a pipe cast in this way before and after heat treatment, and a tabulated comparison of the mechanical

properties of a De Lavaud tube and one cast in the ordinary way. The comparison is all in favour of the centrifugally cast tube.

J. E. Hurst, *Large Diameter Centrifugal Pipe* (Iron Age, June 11, 1925, vol. 115, pp. 1704-1706). Particulars are given of the Hurst-Ball centrifugal casting system which has recently been applied to the production of spigot and socket pipes of large diameter. The process is in operation at the works of the Centrifugal Castings Ltd., Kilmarnock. The pipes produced are of soft grey cast iron and do not require subsequent annealing. The type of pourer is a development of the tilting trough type which has been used in many cases. The original idea in the development of the Hurst-Ball pourer was to form a weir edge in a series of steps varying in height along the length of the trough. In the form as adopted in practice, the cylindrical wall of the trough is cut away in such a manner as to leave a weir edge which is more or less a portion of a helix. On partial rotation of this tilting trough, the molten metal first flows over the lowest edge and successively over the edge of higher levels as the rotation is continued until the whole of the metal is deposited over the surface of the mould in a continuous series of annular rings of a width depending upon the length of each "step-like" weir edge. By allowing the molten metal to flow down this tilting trough at a constant rate, the metal is deposited evenly over the whole surface of the rotating mould.

C. Pardun, *Progress in Centrifugal Casting* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1178-1180). The various methods that have been more or less successfully tried for the centrifugal casting of pipes are described. The chief difficulty in all systems hitherto developed is that, owing to the chill effect on the metal as it runs into the rapidly revolving moulds, the pipes have afterwards to be annealed. Moore has tried to overcome this by using a sand-lined iron mould, the sand lining being formed on a jarring moulding machine, but it has to be renewed for every cast. For 12-foot pipes as used in the English-speaking countries the difficulty is not so great, but in Germany it is the practice to use 16.5-foot pipes, and for these the sand-lined moulds present great difficulties. In a process brought out under the name of Henry-Weitling-Peake (Iron Age, Dec. 25, 1924, vol. 114, p. 1674) an attempt to avoid subsequent annealing is made by preheating the moulds to a high temperature. But means have to be provided for the even distribution of the heat introduced by each cast. In the process in question mercury is used to conduct away the heat. Several improvements aim at prolonging the life of the moulds, for instance, by the use of two concentric tubes, the inner one of a special material like nickel-chrome steel, the outer one of ordinary steel. When the inner one becomes worn it can be replaced without having to renew the whole mould. A space may be left between the two tubes, which is filled with mercury, so as to allow for unequal contraction and expansion. A nickel-chrome steel mould is said to be good for 1500 to 1800 casts.

C. Pardun, *Innovations in Centrifugal Casting* (Foundry Trade Journal, Aug. 27, 1925, vol. 32, pp. 175-176). An abstract in English of the foregoing paper in Stahl und Eisen, reviewing recent developments in the centrifugal casting of metals.

W. R. Martin, *The Davis Steel Wheel and its Manufacture in England* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 27-37).

Malleable Cast Iron.—C. J. McNamara and C. H. Lorig, *A Consideration of the Annealing Operation in the Malleable Foundry* (Paper read before the American Foundrymen's Association, Oct. 1925). The authors have carried out experiments in order to determine the rate of graphitisation of white cast iron. Test specimens were removed from the oven at various periods of the annealing operation, and were quenched in order to preserve the structure present at the time of removal. Graphitisation begins very soon after the temperature has risen above the transition point. In the early stages the reaction proceeds rapidly, but gradually slows down as the equilibrium point is reached. Photomicrographs are included in the paper, showing the structure of the specimens after removal from the oven at varying intervals of time. The results show that it requires nearly sixty hours at a temperature of 1500° to 1550° F. to ensure freedom from primary cementite. Continued slow cooling below the critical point has little purpose in the production of good malleable cast iron.

A. Hayes, E. L. Henderson, and G. R. Bessmer, *The Effects of Some Modifications of a Rapid Annealing Method on the Physical Properties of Malleable Iron* (Paper read before the American Foundrymen's Association, Oct. 1925). A preliminary report of an investigation in progress.

A. Hayes and H. E. Flanders, *One of the Causes of Variations in Rates of Graphitisation of White Cast Iron* (Paper read before the American Foundrymen's Association, Oct. 1925). The authors have studied the factors that cause variations in the rate of graphitisation. The results of experiments indicate that sulphur has a great influence on the rates of graphitisation, and the difficulty can be corrected by the presence of manganese.

A. Hayes and G. C. Scott, *The Catalysis of the Graphitisation of White Cast Iron by the Use of Carbon Monoxide, Carbon Dioxide Mixtures when applied under Pressure* (Paper read before the American Foundrymen's Association, Oct. 1925). The authors have investigated the influences of annealing oven atmospheres upon the production of malleable cast iron. It has been suggested by Honda and Murakami (this Journal, 1920, No. II. p. 287) that carbon monoxide and carbon dioxide act as a catalyst in breaking down iron carbide. The results of experiments show that at temperatures of 927° C. carbon monoxide, carbon dioxide mixtures increase the rate of absorption of free iron carbide by nearly 100 per cent. During cooling at rates varying from

3½° C. per hour to 400° C. per hour, it inhibits almost completely graphitisation in the critical range. The action of the gas mixture offers a very convenient method of obtaining a pearlitic matrix in the partial graphitisation of white iron.

F. A. Melmoth, *Electrically Produced Blackheart Malleable* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Oct. 15, 1925, vol. 32, pp. 325-328). The author discusses the possibilities of the electric furnace for the production of iron for malleabilising by the blackheart process. As the process depends upon a change of condition of the carbon content, induced by the effect of annealing temperature and time and the silicon content, the control of the silicon and carbon in the furnace becomes of the utmost importance. Experiments show that the electric furnace can be successfully used for the manufacture of blackheart castings. No detrimental action either by arc effects or furnace atmosphere appears to affect the product and cause difficulty in annealing.

H. A. Schwartz, *Short-Time Malleabilising of Cast Iron* (Mechanical Engineering, Aug. 1925, vol. 47, p. 623). The reactions involved in malleabilising cast iron are discussed briefly, and the author shows that cooling must not be allowed to proceed more rapidly than will allow the excess carbon to separate, when in the neighbourhood of the A1 point, about 760° C. He emphasises the need for a sufficient safety factor to allow for unexpected variations in operating conditions.

W. Schneider, *Practice in the Manufacture of Malleable Castings* (Giesserei Zeitung, July 1, 1925, vol. 22, pp. 381-387). A general description is given of the methods of manufacture and properties of malleable castings.

E. Schüz, *The Shrinkage of Malleable Castings* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1189-1195). The material examined consisted of metal from the open-hearth furnace only, corresponding to that used for whiteheart castings and blackheart castings in Europe and America. The average composition of the whiteheart cast iron was: Total carbon 2.74, silicon 0.75, manganese 0.115, phosphorus 0.074, sulphur 0.092 per cent. After annealing, the total carbon was 0.44, the temper carbon being 0.13 and the combined carbon 0.31 per cent. The blackheart cast iron contained carbon 2.29, silicon 1.25, manganese 0.33, phosphorus 0.094, sulphur 0.044 per cent. In the annealed casting the temper carbon was 1.24 and combined carbon 0.28 per cent. The shrinkage of the raw white iron averaged 1.93 per cent., and rather more for thin-walled pieces (7 millimetres), and rather less for thick-walled (15 millimetres). Annealed whiteheart castings shrunk more, the shrinkage averaging 2 per cent. The shrinkage of blackheart cast iron averaged 1.89 per cent., thin-walled pieces rather more and thick-walled rather less. Annealed blackheart castings had an average shrinkage of 1 per cent. The shrinkage is less, the higher the temper carbon in the casting, and is greater as the

decarburisation is carried further. This accounts for the difference in the shrinkage of thin-walled as compared with thick-walled pieces.

F. H. Hurren, *Malleable Iron* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, June 11, 18, 1925, vol. 31, pp. 499-502, 526). The important factors involved in the production of malleable cast iron are discussed.

Cleaning of Castings.—U. Lohse, *Modern Equipment for Cleaning Castings* (Stahl und Eisen, Oct. 1, 1925, vol. 45, pp. 1661-1666). The author describes the equipment of the cleaning department of a modern foundry. The cleaning tables consist of grids, beneath which are placed hoppers. The dust, dirt, sand, and iron particles are collected in boxes under the hopper, and an open rising tube is fixed in the centre of the bottom of the box, down which the light dust is drawn by means of a fan. The boxes when full are tipped on to conveyors, the iron is removed by a magnetic separator, and the remainder is discharged into wagons for removal. Sand-blasting apparatus is also illustrated and described.

H. Orr, *Sand-Blasting Castings* (Foundry, Sept. 15, 1925, vol. 53, pp. 747-749, 751). The author outlines the different systems of sand-blasting for the cleaning of castings.

Cutting Cleaning Room Costs (Iron Age, July 2, 1925, vol. 116, pp. 1-4). An illustrated description is given of the methods and plant installed at an American foundry for the cleaning of automobile cylinder castings.

Foundry Equipment.—F. Meissner, *A Modern Foundry for Heavy Machine Castings and Ingot Moulds* (Stahl und Eisen, Aug. 27, 1925, vol. 45, pp. 1470-1476). The author describes the newly laid out foundry of the Rheinische Stahlwerke at Duisburg, including the transport arrangements, the cupola plant, the sand-dressing plant, and the moulding and cleaning departments. The capacity of the foundry is 40,000 to 50,000 tons of castings a year.

Britain's Largest Malleable Iron Foundry (Foundry Trade Journal, July 2, 1925, vol. 32, pp. 9-15). An illustrated description is given of the lay-out and equipment of the Leys Malleable Foundries at Derby, where the manufacture of blackheart malleable castings is carried out.

A Malleable Cast Iron Foundry of the Most Modern Type (Stahl und Eisen, Aug. 27, 1925, vol. 45, pp. 1479-1481). This is an illustrated description of the foundry of the Pacific Malleable Castings Company at Oakland, California, which has already appeared elsewhere (Foundry, Jan. 15, 1925, vol. 53, pp. 56-60).

Operations in a Modern Foundry (Machinery, July 30, 1925, vol. 26, pp. 545-551). Messrs. Morris Motors, Ltd., Cowley foundry was established in 1919, and the advantages obtained by confining their attention to the production of a limited variety of castings are discussed

in the article. The paper treats of the production and use of the moulds required and the general lay-out of the foundry.

M. F. King, *Lining Furnace Bungs* (Iron and Steel of Canada, July 1925, vol. 8, pp. 140-141). For some time past the Canadian steel foundries have been using monolith linings in place of firebricks for these bungs because of the lower cost of the refractory material, lower labour cost, and greatly increased service. The monolith consists of crushed old firebrick bonded with hytempite, and is rammed in place with an air hammer to a depth of 9 inches. The refractory material is prepared by crushing the old firebrick to pass a $\frac{1}{4}$ -inch mesh; it is then put in a cement mixer along with diluted hytempite in proportions of 3000 lbs. of brick to 100 lbs. of hytempite. To each batch of this size is added half a bag of Portland cement, when the mixture is ready for ramming. Wood forms are fastened to the bungs and the material dumped in and rammed; more is added and rammed, and layers laid on until the total thickness is 9 inches. The air-hammer used does not ram directly on to the material: a board which can be moved about is used so as to distribute the blow more evenly.

C. H. S. Tupholme, *Lifting Magnets for Handling Pigs and Castings* (Foundry Trade Journal, Oct. 8, 1925, vol. 32, pp. 305-307).

PRODUCTION OF STEEL.

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I.—PROCESSES OF STEEL PRODUCTION.

Crucible Steel.—*Notes on Graphite Crucibles* (Foundry Trade Journal, Aug. 6, 1925, vol. 32, pp. 124–125). Brief notes are given of the production, requirements, and handling of graphite crucibles.

Bessemer and Open-Hearth Processes.—P. Oberhoffer and A. Wimmer, *Influence of Temperature and Chemical Composition on the Viscosity of Iron* (Stahl und Eisen, June 18, 1925, vol. 45, pp. 969–977). In a previous report by O. Holz (Stahl und Eisen, Sept. 15, 1921, vol. 41, p. 1285) the conclusion was reached that the viscosity of the pig iron in the basic Bessemer process plays a very important part, and for the process to work successfully the first condition is that the metal should be as hot as possible and of great fluidity. No attempt was, however, made to measure the viscosity of the charge, and the object of the present authors has been to devise a practicable method for measuring the viscosity of molten iron or steel. Two lines of investigation were considered: the capillary method, and the method according to which a pendulum is caused to vibrate within the molten mass and the viscosity is determined by the rate at which the vibrations are damped out. The latter plan was chosen. A viscosimeter was constructed, consisting of a crucible to contain a definite amount of molten metal and a pendulum with two bobs suspended above it, the upper one being a steel cylinder, while the lower, a much smaller one, was of a special refractory material with a smooth surface. This lower bob was also cylindrical and was immersed in the liquid metal to a depth of 20 millimetres. Temperature measurements were made by means of a thermo-element protected by a magnesia tube. With this apparatus three series of experiments were made to determine the influence of temperature on the viscosity of pure iron-carbon alloys, the influence of various elements on the viscosity of iron-carbon alloys, and the investigation of a number of samples of basic and acid Bessemer steel. In the case of irons containing 2·50 and 3·45 per cent. of carbon the coefficient of viscosity

remained about the same for the temperature range 1440° to 1385° C. It fell slightly from 1385° to 1340° , from 1340° to 1325° a sudden increase in viscosity took place, and from 1325° to 1305° the curve fell almost vertically. Measurements to ascertain the effect of adding silicon and manganese failed on account of the immediate formation of thin slag layers, which interfered with the pendulum vibrations. Phosphorus and carbon in general increase the viscosity of iron, sulphide of iron lowers it, and the separating out of manganese sulphide is associated with a very marked increase in viscosity. It was further found that the temperature of the commencement of solidification of iron was lowered 17.5° C. for each 0.1 per cent. carbon added, 1.9° for each 0.1 per cent. phosphorus, and 5.5° for each 0.1 per cent. sulphur. The results of viscosity tests on ordinary pig iron are also given.

E. Herzog, *The Efficiency of Converter Installations* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1122–1125). The efficiency of the converter is considered from the point of view of the requirements in the matters of blast, lining renewals, and changing of bottom in relation to the hourly output.

H. Folkerts, *Converter Blowing* (Stahl und Eisen, June 11, 18, 1925, vol. 45, pp. 921–929, 984–992). Trials in blowing converters under different conditions show that considerable economies and a better quality of steel may result from proper attention to certain points in the design of converter bottoms and methods of blowing. The blast should be maintained perfectly regular, so as to supply an unvarying quantity of air to the bath from second to second and the optimum quantity for each converter should be definitely ascertained and adhered to. The friction in the nozzles should be reduced to the lowest degree possible. The air should be injected in concentrated jets. The distribution of the nozzles in the bottom should be such that the liquid charge has the freest access to all the air-jets, and the air-jets should not cross one another in the bath. The bath depth, which usually corresponds to a ferro-static pressure of 1.34 to 1.60 kilogramme per square millimetre, might with advantage be increased; this would increase the energy of movement and lead to economy. The blast should be introduced as cold as possible, to save wear of nozzles. Apparatus should be provided for measuring the amount of blast per second, the blast pressure, the waste-gas composition, and the progress of oxidation. Circulation and vigorous movement of the bath is promoted by making it narrower at the level of the bottom and wider at the bath surface.

H. Bansen, *Dimensions and Output of German Open-Hearth Furnaces* (Iron and Coal Trades Review, Sept. 4, 1925, vol. 111, pp. 351–355). An English translation of an important paper published in Stahl und Eisen, Apr. 2, 1925, vol. 45, pp. 489–507 (see this Journal, 1925, No. I. p. 513).

H. Bansen, *Output and Efficiency as the Basis of the Design and*

Calculation of Open-Hearth Furnaces (Stahl und Eisen, May, 7, 14, 21, 1925, vol. 45, pp. 702-715, 748-756, 789-799). All the conditions for the economical working of open-hearth furnaces are reviewed, and the factors which influence output and efficiency are discussed. The paper is a continuation of the author's work on open-hearth furnace design.

Enlarge Southern Steelworks (Iron Trade Review, Oct. 1, 1925, vol. 77, pp. 826-828). An installation of four stationary open-hearth furnaces has recently been put in operation at the Fairfield works of the Tennessee Coal, Iron and Railroad Co. The ore and scrap process is used, and the furnaces use either coke-oven gas or tar. By a slight alteration in the burner orifice fuel oil can be used instead of tar. The burners are water-cooled, and both the tar and gas are reversed by two steam cylinders. The regenerator chambers are built on converging angles so that the regenerators and stack flues form a Y, thus giving the most direct route to the stack. Three of the furnaces are equipped with waste-heat boilers.

F. J. Crolius, *A Heat-Balance Open-Hearth* (Blast-Furnace and Steel Plant, May 1925, vol. 13, pp. 190-192). The article describes briefly an open-hearth furnace designed to do away with troublesome reversing valves controlling the passage of air and waste gases through the regenerators. This is accomplished by building a short stack to each regenerator and placing two identical reversible fans one in each flue. Thus one blows the incoming air while the other exhausts the waste gases; on reversal the fans exchange duties and the air and waste gases move in the opposite direction. More complete furnace control as well as greater economy are claimed, and figures are tabulated in support of this contention.

G. R. McDermott, *Open-Hearth Pressure Control* (Blast-Furnace and Steel Plant, June 1925, vol. 13, pp. 230-232). An account is given of the performance of an open-hearth furnace before and after the installation of a turbo-blower and constant-volume air governor on the gas-producer which supplied gas to the furnace. An explanation is given of the effects of fluctuations of back pressure, &c., on the efficiency of the gas-producer. In the jet type of blower the steam is used directly to draw in the air, and so a variation of steam pressure at the jet, and of the back pressure, will cause an alteration in the rate of gasification. Further, there will be a disturbance of the ratio of air to steam, producing a lean gas with high hydrogen and carbon dioxide contents, which will then call for a higher driving rate and consequent loss of efficiency. On the other hand, too little steam may cause clinker to form. These troubles are overcome at the plant described in the article.

F. Fiorelli, *Open-Hearth Furnace with Recuperative Firing* (Metalurgia Italiana, 1924, vol. 16, pp. 446-457). The author describes and illustrates an open-hearth furnace designed on the recuperative principle. The furnace has four recuperators and two ordinary regenerator chambers. The gas is preheated in the two outside recupera-

tors and the air is heated in two stages, first in the regenerators and then in the inside recuperators. The fuel gas leaving the recuperator is calculated to have a temperature of 1350° and the air about the same temperature. The products of combustion are stated to enter the recuperator at 1550°C .

R. Schenck, *Use of Oxygen and Oxygen-Enriched Air in the Steel Refining Processes* (Stahl und Eisen, Sept. 17, 1925, vol. 45, pp. 1596-1602). By blowing a gas-producer with air enriched with oxygen the calorific value of the gas can be much increased, but if the oxygen percentage becomes high the temperature within the producer is likely to be such that the lining will be destroyed. By mixing carbon dioxide or waste gases with the enriched air the temperature would be lowered without diminishing the yield of CO. The mixing of steam with the enriched air would also give a gas of high value. The following values have been calculated as showing the comparative cost per 10,000 calories of ordinary producer-gas and a gas made by blowing with commercially pure oxygen and steam.

	Ordinary Power Gas. Per Cent.	Oxygen and Steam Power Gas. Per Cent.
CO	24.5	41.07
H ₂	17.8	39.92
CH ₄	3.6	6.04
C ₂ H ₄	3.2	5.35
CO ₂	3.7	6.16
O ₂	0.4	0.65
N ₂	46.8	0.81
	100.0	100.0
Cal. value	2030 Cals.	2970 Cals.
Cost per 10,000 Cals.	0.60d.	0.73d.

By using an oxygen-enriched gas the preheating of the gas and air supply to an open-hearth would not be necessary; if preheating is retained, the more rapid melting of the charge and increased speed of reactions would shorten the period of a heat and so increase the efficiency of the furnace. It would be possible to attain temperatures equal to those of the electric furnace.

R. Dawidowski, *Isotherms of the Flame Stream in Metallurgical Furnaces* (Stahl und Eisen, July 23, 1925, vol. 45 pp. 1265-1273). A discussion of Groume-Grjmailo's theory of the propagation of flame according to the laws of hydraulics and of Esmann's mathematical calculations of furnaces based on that theory. A number of experiments are described, with diagrams, in substantiation of Groume-Grjmailo's fundamental principles. A special furnace was constructed with gas-producer attached. The inside wall was marked off in squares, and at the corners of each square was a small peep-hole fitted with a disc against which a Wanner optical pyrometer was placed. In this way the temperature of the flames throughout the length of the furnace could be read, and the course of the flames was plotted according to the

isothermal strata as they swept through the furnace. The observations confirm the applicability of the laws of hydraulics to the flow of flames through a furnace.

J. Guyot, *The Dissociation of Producer-Gas in its Passage through the Regenerators of Open-Hearth Furnaces* (Revue de Métallurgie, Mémoires, Aug. 1925, vol. 22, pp. 515-520). Systematic analyses of the gases on their way through regenerators or recuperators have shown that their composition varies, and it has sometimes been ascribed to the leakage of air into the chambers and the consequent oxidation of some of the CO to CO₂. Even if this does occur, which is doubtful, it is by no means the principal factor. Coke-oven gas has been shown by J. Dupuis to dissociate in this way, but the two gases are hardly comparable from this point of view. In experiments undertaken to elucidate the subject it was found that dissociation does actually occur in the regenerators, and that its occurrence is influenced by the presence of oxide dust deposited in the chambers. These dust particles play a double rôle, as they insulate the checkerwork and so interfere with the heat exchanges, and they afford conditions for dissociation reactions which have the effect of increasing the temperature of the combustion of the gas, but what may, in a sense, be gained by the hotter combustion temperature of the gas may be more than lost by its less efficient thermo-chemical composition.

A. Sauveur, *Armco Iron* (Revue de Métallurgie, Mémoires, July 1925, vol. 22, pp. 397-399). A short account of the development of Armco iron. The earliest attempts to produce a rust-resisting pure iron were made by the American Rolling Mill Company, who began operations in a basic open-hearth furnace in 1900. R. B. Carnahan and A. S. Cushman pursued their endeavours, and from 1909 to 1912 patents were taken out and success attained. At first great difficulties were met with. Completely hollow ingots were often produced; the metal was invariably exceedingly wild, but its behaviour and composition are now under complete control. As the manganese is exceedingly low, very little sulphur makes it red-short, particularly during the 1000° to 900° C. temperature range. It is therefore necessary to stop rolling at this interval and recommence after the 900° C. limit has been passed. With only 0.01 per cent. of sulphur this does not occur, even if manganese be absent. This temperature range is that in which minimum malleability occurs in ordinary iron. Armco iron resists rusting well, and its purity renders it twice as electrically conductive as steel. It also welds easily. The charge takes about two hours longer to work than ordinary mild steel.

L. F. Johnson, *The High Points in the Manufacture and Working of Steel* (Transactions of the American Society for Steel Treating, Sept. 1925, vol. 8, pp. 329-339). A general outline is given of open-hearth practice and the rolling and forging of steel.

J. D. Knox, *Metallurgy is Forcing Mystery out of Tool Steel Industry* (Iron Trade Review, Aug. 27, 1925, vol. 77, pp. 485-489). The

practice at the plant of the Vanadium Alloys Steel Co., Latrobe, Pa., for the manufacture of alloy tool steels is described and illustrated.

H. L. Campbell, *Calculating Ferro-Alloy Additions* (Foundry, May 15, 1925, vol. 53, pp. 391-392). The author presents a chart for the rapid calculation of the additions of ferro-alloys required to raise the percentage of any element to the desired amount.

J. B. George, *Calculating Ferro-Alloy Additions* (Foundry, Sept. 1, 1925, vol. 53, pp. 694-696). The preparation of charts for calculating ferro-alloy additions is described. The author submits a chart which he claims is more accurate than the one prepared by Campbell.

R. W. Müller, *Utilisation of Galvanised Iron Scrap* (Chemiker Zeitung, 1925, vol. 49, p. 140). The use of galvanised scrap in the ordinary furnace results in loss of the zinc and damage to the furnace. In the method described by the author ordinary iron scrap and pig iron are melted in an open-hearth furnace in the ordinary way, with the connections to flues and chimney arranged as usual. Before the galvanised scrap is added the dampers are readjusted, so that the furnace is connected with settling chambers and bag filters for the recovery of zinc oxide. For a charge of 10,000 kilogrammes of galvanised scrap the process may last two hours.

E. E. Thum, *Open Notches with Gas Lance* (Iron Trade Review, Sept. 24, 1925, vol. 77, pp. 749-752). The uses of the oxygen torch or lance for opening up tapholes, ladle stoppers, and for other purposes in open-hearth plants are described and illustrated.

A Furnace Repair Gun (Gas Journal, June 17, 1925, vol. 70, p. 938). The Quigley refractory gun, operated by compressed air, enables repairs to be quickly carried out in inaccessible places in furnaces.

E. A. Phoenix, *Reducing Steel Melting Costs* (Iron Trade Review, Sept. 3, 1925, vol. 77, pp. 553-554). The application of insulating materials to open-hearth furnaces is dealt with.

Electric Steel Furnace Practice.—O. v. Keil and K. Hess, *Balance of an Electric Arc Furnace* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1134-1146). An electric balance, heat balance, and charge balance of an arc furnace of the Nathusius type but without bottom electrodes are calculated. The total input of material, including electrode consumption and substance taken up from the hearth, walls, and atmosphere, was 7794.66 kilogrammes, and the total output of material, including volatile matter and dust, was 7779.46 kilogrammes. The actual metallic product consisted of 5752 kilogrammes of chrome-silicon spring steel. By adopting careful means for calculating all losses, particularly radiation, convection, and conduction losses, it was possible to do away with the usual entry of "charge losses." The electric efficiency was 81 per cent., and the total thermal efficiency was 39.9 and 49.7 per cent. The reasons for the low efficiency are discussed.

D. F. Campbell, *A High-Frequency Induction Furnace* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 69-75).

G. de Burlet, *High-Frequency Induction Furnaces* (Revue Universelle des Mines, July 15, 1925, vol. 7, pp. 93-113). An abstract in French of two papers by Ribaud, Professor at the Institut de Physique, Strasbourg. One was published in the Journal de Physique et le Radium (June 1923, series 6, vol. 4, pp. 185-197), and the other in the Bulletin de la Société française des Electriciens (series 4, vol. 3, No. 29, 15 pp.). The abstract gives a description of the various types of high-frequency furnaces and the theory of their working.

D. Willcox, *New High-Frequency Induction Furnaces* (Paper read before the American Foundrymen's Association, Oct. 1925). The author describes a new high-frequency induction furnace for the melting of brass, and briefly discusses the application of this type of furnace for melting nickel iron alloys and special alloys.

G. E. Taylor, *Induction Heating by Low-Frequency Currents* (Electrical Review, Aug. 21, 28, 1925, vol. 97, pp. 285-287, 327-329). A brief history of induction furnaces is given, followed by a fully detailed account of the construction and use of the Ajax-Wyatt furnace. This furnace is expressly designed to melt non-ferrous alloys, especially of the copper-zinc type, which present greater difficulties to the designer of electric induction furnaces on account of their lower resistances to the induced currents and lower power factor. In this type of furnace it is difficult to keep slag properly molten during a refining operation, and so melting only should be attempted.

A. Scortecchi and U. Bonanno, *Considerations on the Consumption of Electrodes in the Manufacture of Steel* (Metallurgia Italiana, Aug.-Sept. 1925, vol. 17, pp. 365-371). The comparative economy of different types of electrodes is considered. The three types compared are the carbon electrode, the graphite, and the Soderberg or continuous electrode. Although the cost of the electrodes themselves are in the proportion of graphite = 5, carbon = 1, and Soderberg = 0.66, the rates of consumption within a closed furnace differ very much for the three types, and taking this difference into account, according to calculations given, the relative costs of the electrodes are as follows: Carbon = 1, Soderberg = 1.53, graphite = 1.61.

Waste-Heat Utilisation.—W. N. Booth, *The Recovery of Waste Heat from Furnaces* (Paper read before the Midland Junior Gas Association, Mar. 27, 1925: Gas Journal, Apr. 1, 1925, vol. 170, pp. 49-53). A consideration of the heat processes involved in a furnace shows that ultimately the only way to increase the amount of heat given up to the furnace chamber and contents is to raise the temperature of the flame gases. The effects of exact air regulation and preheating are shown in the author's graphs. Further improvement can be effected by good furnace insulation; in this connection the surrounding of the furnace by the flues themselves is a very efficient means of preventing excessive radiation from the furnace body. The most economical way of using the waste heat which is contained in the flue gases is

to return it to the furnace. For this purpose regenerators and recuperators are used, and the author describes their theory and practice and relative advantages. The utilisation of the waste heat in other plant, such as boilers, &c., should only be carried out after the greatest possible quantity has been extracted for use again in the furnace itself.

Steel Industries in Various Countries.—A. Pearson, jun., *Proposed Siberian Steel Plant* (Iron Age, Aug. 6, 1925, vol. 116, pp. 339–341). Particulars are given of the proposal to erect a large steelworks at Telbas, in the State of Tomsk. The site of the works is on a bend of the Kondom River, and is adjacent to rich iron ore and coal deposits.

II.—CASTING AND TREATMENT OF INGOTS.

Life of Ingot Moulds.—J. H. Hruska, *Life of Large Ingot Moulds* (Iron Age, Aug. 6, 1925, vol. 116, pp. 345–346). The author has investigated the influence of high-temperature erosion on the life of ingot moulds, and the effect of the chemical composition of ingot mould metal upon the quality of ingot iron and steel. An average analysis of the interior surface of the mould was taken before the first heat was poured, and again after about fifty-eight heats were cast. The changes on the interior surface of the ingot moulds indicate a general outline of the phenomena affecting chemically the mould metal, which might be summarised as follows :

Iron as the dominant constituent, being oxidised, does not change its molecular position. Carbon and manganese show, according to their chemical affinity for oxygen, diffusion toward the higher temperatures, *i.e.* to the hot ingot metal. Almost 90 to 98 per cent. of the total carbon contained in the inner layers of the ingot mould is oxidised to CO_2 . The increase of silicon on the surface might be explained by the tendency to form silicates with MnO-FeO . The increase of sulphur and phosphorus is doubtless the result of diffusion or the tendency to form constituents with hydrogen.

Segregation and Unsoundness in Ingots. O. v. Keil and A. Wimmer, *Note on Ingot and Blowhole Segregations* (Stahl und Eisen, May 28, 1925, vol. 45, pp. 835–837). Ingots of open-hearth steel were examined with regard to the relation of ingot segregation (phosphorus and sulphur) to blowhole segregation. The more pronounced the segregation in the ingot is, the more the blowhole segregation is increased, especially in the case of sulphur segregation. Strongly enriched zones are attributable to blowhole segregation rather than to ingot segregation.

L. Guillet, J. Gallibourg, and Ballay, *Intercrystalline Pipes*; “*Micro-pipes*” (Revue de Métallurgie, May 1925, vol. 22, pp. 253–272). Pipes

or cracks of minute dimensions exist concurrently with ordinary pipes properly so-called, and with blowholes due to bubbles of emulsified gases, or to the escape of such gases, previously dissolved, or formed by reactions which occur during cooling. The classical explanation of the formation of ordinary pipes is extended to these smaller hair-pipes. Other considerations intervene, however, in determining the actual result. These hair-pipes are more likely to occur in steels of complex composition, such, for example, as tool steels. Ingots of such steel often reveal chains of hair-pipes arranged in groups from one end of the axis of the ingot to the other. The leading causes of hair-piping are: temperature of casting; temperature differences between the mould and the metal at the moment of casting; the shape of the casting; the distribution of the isotherms at each moment during solidification; the vertical distance between the solidus and the liquidus; the rate of diffusion of the different constituent elements of the alloy in both the liquid and the solid phases; the heat of solidification; the coefficient of thermal conductivity of the solid and liquid phases; the fluidity of the liquid phase; and the density of the liquid. If some of these factors escape analysis there are nevertheless others which can be studied without much difficulty, in particular cases.

G. Tammann and H. Bredemeier, *Cavities and Channels running out to the Surface of Metals* (Zeitschrift für Anorganische Chemie, 1925, vol. 142, pp. 54-60; Stahl und Eisen, July 9, 1925, vol. 45, p. 1211). An investigation is described which had for its object the determination of the volume of hollow spaces, pores, and channels in metals after solidification or such as may be produced by cold-working. For instance, the so-called Rose's channels are formed by cold-working, and close up again when the metal is subsequently heated. The authors' method for measuring the volume of these channels is to place the metal piece in water coloured with a certain dye and to subject the water to a pressure of 2500 atmospheres. At this high pressure the water absorbs all the air in the hollows, and on removing the pressure the liquid remains in the metal in a metastable condition. The metal piece is then disintegrated by filing into very fine filings, which are leached with water. The amount of dyestuff which is leached out is colorimetrically determined, and from this the volume of the hollow spaces and pores is calculated. The dye solution used is potassium salt of eosin. In order to investigate the increase in volume of a soft iron rod when drawn into wire which, in the case of nickel-iron amounts to about 0.2 per cent., this impregnation method was used. An electrolytic iron wire was drawn down from 10 square millimetres area to 0.8 square millimetres, and one piece was annealed for one hour at 750° in a hydrogen current. The volume of the hollow spaces in the hard-drawn wire was 0.09, and in the annealed wire 0.07 per cent. of the volume of the respective test-pieces. According to density determinations the volume of the hollows in the hard wire should have been 0.2 greater than in the soft wire, and the difference is accounted for by the

supposition that many internal hollows do not run out to the surface. The conclusion is that the volume of the cavities and channels which do run out to the surface is nearly the same in both the hard and the soft wire.

E. L. Reed, *An Investigation of the Properties of Iron-Carbon Alloys Melted in Vacuum and Melted in Air* (Iron and Steel Institute, Carnegie Scholarship Memoirs, 1925, vol. 14, pp. 91-130). A comparative study of the properties of iron-carbon alloys melted in vacuum and melted in air was made with the object of determining the effect, if any, of gases contained in the material, and to compare the results of physical tests for the preparation of the alloys. Electrolytic iron and pure carbon, manganese, phosphorus, sulphur, nickel, tungsten, silicon, and chromium were used. The two series of alloys prepared in vacuum and air were made as nearly identical as possible. The vacuum-melted alloys were much sounder and freer from inclusions than the air-melted specimens, and were also more resistant to corrosion. Dendritic segregation is caused by the condition of phosphorus and nickel, but not by carbon alone or oxygen alone or jointly.

FORGING AND ROLLING-MILL PRACTICE.

Reheating Furnaces.—*New Design of Coal-Fired Furnace* (Iron and Coal Trades Review, July 17, 1925, vol. 111, pp. 87–88). Particulars are given of the experimental work carried out at Brown, Bayley's Steelworks, Sheffield, with a view to improving the efficiency of coal-fired heating furnaces. Complete results are given of the fuel economies effected by different modifications in design. The first experimental furnaces consisted of a pair of "in and out" billet reheating furnaces having preheated secondary air and steam-blown primary air. The recuperators were similar to those adopted with gas-fired furnaces, the secondary air obtaining its heat partly from the waste gases and partly from the furnace walls and roof. With an output of 54·25 tons per week the cost of fuel and steam was 5s. 4½d. per ton. Another pair of furnaces was built in which the primary air, steam blown, was delivered into a chamber under the hearth, where it absorbed a certain amount of heat before passing into the ashpit. A cast iron bearer under the back wall of the combustion chamber prevented air from gaining access to the fire except through the fire-bars. The recuperator chamber was also improved, and the waste gases left the furnace below hearth level. The furnace walls and roof were covered with insulating brick. The cost of fuel and steam in these furnaces was 4s. 4½d. with an output of 56·17 tons. Further furnaces were built having both the primary and secondary air supplied by fan and preheated, the primary air only being partially saturated by means of a water spray introduced in the path of the hot air before it entered the ashpit. The fuel, water, and electric power cost per ton of steel rolled with an output of 31·39 tons of steel per week was under 3s. 2½d. It is intended to erect another furnace provided with a double-row recuperator, this giving a counter-current effect with increased efficiency and higher temperature of air. The design of each furnace is illustrated.

T. R. Speck, *Furnace Design and Performance* (Paper read before the Birmingham Association of Mechanical Engineers: Gas Journal, Apr. 15, 1925, vol. 170, pp. 182–184). The points considered are thermal efficiency, the need for standardised tests, furnace economy, recuperation and regeneration, furnace doors. Comparisons are tabulated showing working performances of several types of furnaces. The paper deals only with gas-fired furnaces.

Automatic Stock-Feeding Furnace (Machinery, July 30, 1925, vol. 26, pp. 560–562). The article describes a furnace and attachments which automatically feeds the stock for bolt-making from coils of wire through

the heating space direct into the bolt-forging machine. The process is continuous, the end of one coil of wire being welded to the next, and the output of bolts up to $\frac{1}{2}$ inch diameter is nearly double that possible with hand-feed machines.

E. H. Koenig, *Efficiency of Heating Furnaces* (Iron Trade Review, July 30, 1925, vol. 77, pp. 249-253). A comparison is made of the performance of continuous and intermittent types of heating furnaces. Detailed operating records of both types of furnaces are tabulated. The thermal efficiency of furnaces fitted with waste heat boilers is also dealt with.

The Preheating of Air for Furnaces (World Power, May 1925, vol. 3, pp. 293-294). A description and sectional photograph are given of the Howden-Ljungström air preheater made by Messrs. James Howden & Co., Ltd. Metal plate surfaces are caused to revolve in such a way that each part is carried alternately into the current of waste gases and then into the incoming cold air. The heat from the waste gases is thus transferred mechanically to the air, and is not conducted through partitions.

Forging, Pressing, and Stamping.—F. H. Colvin, *Forging Crankshafts for Large Diesel Engines* (American Machinist (European Edition), Aug. 8, 1925, vol. 63, pp. 3-5).

F. H. Colvin, *Forging and Machining Connecting Rods* (American Machinist (European Edition), Aug. 29, 1925, vol. 63, pp. 155-157). The two articles describe the method of manufacture adopted by Messrs. Fairbanks, Morse & Co. at their works at Beloit, Wisconsin, U.S.A.

A. O. Schaefer, *The Manufacture and Heat Treatment of Large Forgings* (Transactions of the American Society for Steel Treating, June 1925, vol. 7, pp. 699-717). The heating and forging of large ingots is discussed in detail. Melting practice, ingot mould design, methods of pouring, and the heat treatment and testing of forgings are also considered.

F. T. Sisco, *The Manufacture of Iron and Steel* (Transactions of the American Society for Steel Treating, Sept. 1925, vol. 8, pp. 357-373). In this, the second of a series of articles, an account is given of the mechanical treatment of steel, including forging, rolling, and cold-working.

D. L. Mathias, *Material Handling in Upset Forge Plant* (Forging, Stamping, Heat Treating, May 1925, vol. 11, pp. 146-152). The article details the plant and equipment of the American Forge Company, Chicago, which is the largest devoted exclusively to the manufacture of upset forgings. By careful attention to the lay-out of the shops and the provision of suitable facilities for handling the material a high efficiency is attained.

Drop-Forging Turbine Blades (Forging, Stamping, Heat Treating, May 1925, vol. 11, pp. 155-165). A description of plant for the

manufacture of turbine blades by drop-forging, belonging to the Westinghouse Electric and Manufacturing Company, at their South Philadelphia Works.

J. F. Harper, *Defects in Large Forgings* (Mechanical Engineering, May 1925, vol. 47, Section 2, pp. 400-402). Defects in forgings are classed by the author under two heads: those inherent to the material, and those caused by the method of manufacture. Under the first head are placed: Variations in composition, piping and gas pockets, cracks and slaglines and "ghost lines." In the second group occur: Laps, star cracks, clinks, improper reduction and heat treatment. All these kinds of defects are described, together with their causes, and the manner in which to obviate them.

Modern Forge Plant for Heavy Work (Forging, Stamping, Heat Treating, May 1925, vol. 11, pp. 180-184). An illustrated description of the new plant of Messrs. A. Finkl & Sons, Chicago. The heating furnaces are of interest. In order that no unheated air may filter in through doors or observation holes in the heating furnaces, these are worked on a balanced draught; oil burners are used, and these are surrounded by a steam jacket which prevents the burning of the burner tips and superheats the steam used for atomising the fuel. The regenerators are above the ground level; they are designed to work on a definite reversal period of fifteen minutes and the resulting saving on fuel consumption is very considerable.

E. V. Crane, *Power Presses—Their Use in Industry* (Forging, Stamping, Heat Treating, June 1925, vol. 11, pp. 213-217). The article describes some of the many uses to which power presses may profitably be put.

R. I. Miner, *Review of Pressed Metal Developments* (Forging, Stamping, Heat Treating, Aug. 1925, vol. 11, pp. 282-283).

A. R. Kelso, *Review of Coining-Press Developments* (Forging, Stamping, Heat Treating, May 1925, vol. 11, pp. 173-179. Reprinted from the Journal of the Society of Automotive Engineers). The paper summarises the increase in production which has been attained by the adaptation of the coining-press to the manufacture of such parts as forged arms and levers. Machines are made capable of exerting a pressure up to 2000 tons per square inch of area of the part squeezed. The composition of the dies is specified and feeding mechanism described. The effect of this pressing on the internal structure of the metal has been studied, and there is no difference in the molecular constituency of the parts after squeezing.

R. T. Rolfe, *Some Notes on Bright Drawn Steel* (Metal Industry, July 31, Aug. 7, 1925, vol. 27, pp. 101-102, 125-127). The author tabulates and discusses the wide range of properties that may be found in commercial bright drawn steels. Some are too tough and give trouble in machining; others are too brittle and have practically no impact value. A more standard composition and method of manufacture is highly necessary.

R. T. Rolfe, *A Further Note on Bright Drawn Steel* (Metal Industry, Oct. 9, 1925, vol. 27, pp. 343-344). The author adds further examples bearing out the statements made in his previous article. A small table of typical bright drawn steels on the market is added.

Rolling-Mill Equipment.—*34-Inch Universal Rolling-Mill* (Engineering, July 10, 24, Aug. 7, 21, 1925, vol. 120, pp. 36-38, 93, 156-158, 222-224). A description of the alterations carried out at Messrs. Stewarts and Lloyds, Ltd., Mossend Works, and of the modern rolling-mill plant that has been installed there, together with illustrations, is published.

Universal Plate Mill Electrical Equipment at Messrs. Stewarts and Lloyd's Mossend Works (Iron and Coal Trades Review, July 24, 1925, vol. 111, p. 139). Particulars are given of the electrical driving equipment of this mill.

Skelp Mill at the Works of Alfred Hickman Branch of Stewarts and Lloyds, Ltd. (Iron and Coal Trades Review, Aug. 14, 1925, vol. 111, pp. 243-245). Illustrated particulars are given of the general arrangement of the Morgan continuous 12-inch skelp mill in operation at these works.

Electrically-Driven Hoop and Strip, and Rod Mills at Newport Mills, Middlesbrough (Iron and Coal Trades Review, July 10, 1925, vol. 111, pp. 49-50). The rolling-mills of Richard Hill & Co., Ltd., have recently been changed over from steam to electric drive. The new electrical driving equipment is described and illustrated.

New Plant at the Baracaldo Works of the Altos Hornos de Vizcaya (Iron and Coal Trades Review, Aug. 28, 1925, vol. 111, pp. 320-321). The most important sections of this new plant are the reversing rolling-mills; the section finishing shops and despatch yard for rolled products; the open-hearth shop and the laboratory. Particulars are given of these sections, which are in course of construction. Alterations to the blast-furnace charging equipment, the utilisation of slags, appliances for the transport of waste material, and a new battery of coke-ovens are projected.

Eight-Inch Merchant Bar Mill (Iron Age, July 23, 1925, vol. 116, pp. 201-204). The lay-out and equipment of the bar mill of the Donner Steel Co., Buffalo, is described and illustrated. There are two groups of continuous rolls of three and four stands respectively, and seven stands of looping rolls. The heating furnace is fired with coke-oven gas and tar, and occasionally with oil.

E. R. Norris, *Repairs to Rolling-Mill Engine Shaft* (Blast-Furnace and Steel Plant, May 1925, vol. 13, pp. 193-194). Details are given of a repair carried out on a 17½-inch engine shaft. As the replacement of the shaft would have involved a 40,000 lbs. forging, and machining it to fit various parts carried on it, including a 50-ton sectional rope wheel, besides dismantling and reassembling, this would have meant four to six weeks' loss of time. The method adopted was to weld a

flange by means of thermit to the large part of the shaft which carried the rope wheel, and a conveniently placed gear hub was used as the companion flange, the two being bolted together. The whole repair occupied 147 hours and cost only \$4488 as against an estimated \$13,000 for a new shaft, not including the extra loss of time which would have resulted had a new shaft been fitted.

H. Harris, *Why Hard Chilled Rolls become Rough* (Forging, Stamping, Heat Treating, Aug. 1925, vol. 11, pp. 275-276). The author attributes much of the roughening of rolls to bad manipulation by the operator of the mill. He declares that uniformity of roll temperature is essential to successful operation, and care taken in the warming of the rolls and the use of cooling water will eliminate many failures.

Rolling of Steel.—H. D. Hibbard, *Surface Cracks in Rolling Steel* (Iron Age, June 25, July 9, 1925, vol. 115, pp. 1837, 1879-1880, vol. 116, pp. 77, 124-125). A discussion of the types of cracks appearing in finished rolled products, their causes and methods of their elimination. The cracks or tears may be distinguished as, or due to: Snakes, cold shut, tear from hanging in the mould, too rapid heating of cold ingot, red-shortness, burning or overheating, dendrites, skinholes, and tears in parts which are stressed without work.

N. Metz, *Experimental Researches on the Hot-Rolling of Iron* (Revue de Métallurgie, Mémoires, Jan., Feb. 1925, vol. 22, pp. 1-20, 66-87). Reference is made to earlier experiments in which screws placed cold in bars of iron were, on rolling, employed to reveal the modes of deformation undergone by the metal. Further experiments are now described, having as their object the checking of the previous results and the investigation of the phenomena of spread in rolled bars. Both holes and screws were used, the holes being at carefully measured distances apart. After rolling, the differences in their diameters and in the relative positions of the screws were again carefully measured. The experiments with screws were found inconclusive; bars in which holes had been bored gave better results. In some of the experiments the surfaces and the central axes of the bars were at different temperatures. Many tables are given showing the draft put on the bars, the temperatures of rolling, and the degrees of deformation. The following general conclusions emerge from the experiments:

1. A bar during rolling widens more in proportion as the temperature of rolling decreases; on the other hand, the displacement remains invariable.

2. The lateral surfaces are more regular (plane) the higher the rolling temperature. At normal temperatures they have a tendency to convexity; at high temperatures, to concavity.

3. The widening is a function of the coefficient of friction between the bar and the rolls, and increases as the friction diminishes. Hence chilled rolls tend to widen the piece more than ordinary rolls, and widening assumes a maximum when steel rolls are used.

4. Widening increases with the pressure, and so likewise does the tendency to convexity in the lateral surfaces of the sections.

5. It likewise increases in proportion as the diameter of the rolls increases.

6. A given reduction in the height of the piece will be accompanied by a degree of widening which increases with the number of passes made.

7. For a given coefficient of elongation, widening increases in proportion as thickness diminishes.

8-10. Widening occurs differentially in different parts of the section, depending on the degree of pressure exerted.

11. The higher the speed of rolling the less the widening effect.

New Plant Rolling Charcoal Iron (Iron Age, May 21, 1925, vol. 115, pp. 1486-1488). A description is given of the practice at the works of the Reading Iron Company, Reading, Pa., for the production of charcoal iron. The knobbling process is used, the resultant blooms of iron being hammered and then rolled in a bar and skelp mill. Charcoal and scrap are charged into bloomery furnaces, and as the melting proceeds further additions of scrap and charcoal are made until there is formed at the bottom of the hearth a mass of iron about 300 lbs. in weight. These lumps are forged into blooms about 6 inches square. They are then transferred to a heating furnace and afterwards rolled into bars of varying widths, the range being 4 to 8 inches. The bars are again reheated and passed through an 18-inch skelp mill. The same plant is also described by E. C. Kreutzberg, *Replaces Forge Plant with Charcoal Bloomery* (Iron Trade Review, May 21, 1925, vol. 76, pp. 1319-1321).

H. Preussler, *Plastic Deformation* (Stahl und Eisen, Aug. 20, 1925, vol. 45, pp. 1422-1428). A discussion of the laws of deformation of material and of the influence of compression by direct pressure and by rolling. The application of a knowledge of these laws to forging, pressing, drawing, and rolling-mill operations is considered.

E. Siebel, *Forces and Flow of Material during Plastic Deformation* (Stahl und Eisen, Sept. 10, 1925, vol. 35, pp. 1563-1566). A consideration of the laws of plastic deformation of hot material during rolling and working, with mathematical calculations of the forces, their distribution and direction, which produce deformation in rolling.

W. Tafel, *The Theory and Practice of Rolling Steel* (Iron Trade Review, Sept. 17, 1925, vol. 77, pp. 677-679). The first of a series of articles which, when completed, will form a full English translation of the author's well-known book on the principle and practice of rolling steel. The translation is made from the German by R. Rimbach.

J. R. Freeman, jun., and R. D. France, *Comparative Cold-Rolling Tests of Open-Hearth Steel Strip (Deep Drawing Stock) and Electrolytic Iron Strip* (United States Bureau of Standards, 1925, Technologic Paper, No. 288). Tests were carried out to determine the relative cold-rolling properties of electrolytic iron and open-hearth steel strip especially adapted for deep-drawing operations. Both types of material

were cold-rolled under identical conditions. The materials were rolled under both mild and very severe conditions. The rolling tests did not indicate any marked difference between the two types of material. Mechanical tests were carried out on specimens representing all stages of the rolling tests. These included hardness tests; Erichsen cupping tests; tensile tests, both longitudinal and transverse to direction of rolling; and bend tests. These tests showed that electrolytic iron does not harden so rapidly and does not increase in tensile strength as rapidly with cold-rolling as open-hearth steel. The tensile strength of cold-rolled strip was higher in the direction transverse to rolling as compared with that in the direction parallel to rolling. The hardness was found to approach a maximum with increasing total reductions and then to decrease with further cold-rolling. In general, the tests indicate that electrolytic iron would probably be slightly superior to commercially obtainable open-hearth steel for deep drawing operations.

Seamless Tubes.—*Manufacture of Seamless Tubes* (Stahl und Eisen, Sept. 24, 1925, vol. 45, pp. 1632–1639). The article gives an account of the manufacture of seamless tubes as practised at the works of the Weldless Tube Company, based on descriptions by E. R. Kelso (Iron Age, Jan. 3, 10, 1924, vol. 113, pp. 57–60, 159–162), by E. F. Ross (Iron Trade Review, June 28, 1923, vol. 72, pp. 1877–1882), and by B. W. Chancellor (Iron and Coal Trades Review, Sept. 26, 1924, vol. 109, pp. 510–512). The methods used are chiefly those of the well-known Mannesmann system, and the apparatus is well illustrated. Some results of mechanical tests on cold-drawn tubes and on tubes after annealing are given.

D. L. Mathias, *Fabricating Seamless Hollow Metal Balls* (Forging, Stamping, Heat Treating, Apr. 1925, vol. 11, pp. 118–120). A description is given of the method of making hollow metal balls from strip or seamless tube. Perfect balance and freedom from internal strain is claimed without affecting the strength or accuracy of the ball. The metal is cold-worked throughout.

Manufacture of Wire.—H. Altpeter, *The Manufacture of Wire from Low Carbon and High Carbon Steel* (Stahl und Eisen, Apr. 16, 23, 1925, vol. 45, pp. 569–581, 614–625). The author gives a general description of modern practice in the drawing of steel wire from steel containing 0·06 to 0·12 per cent. carbon and from steel with 0·85 to 0·95 per cent. carbon. The operations involved in drawing wire from 15 millimetres to 0·1 millimetre diameter, including pickling, annealing, patenting, and coating, are fully described, with illustrations of plant and improved types of drawing machines, pot annealing furnaces, furnaces and lead baths for the patenting process, and many other details.

A. Pomp, *Theory and Practice in the Manufacture of Steel Wire* (Stahl und Eisen, May 21, 1925, vol. 45, pp. 777–785). Some historical notes with illustrations are given concerning the early modes of making

wire. A short description of modern practice follows dealing with the manufacture of low carbon steel wire. The flexibility and hardening capacity of steel wire depend very much on the structure. Defects such as surface decarburisation, overheating, hardening cracks, and black fracture are illustrated, and precautions for their avoidance are explained. The patenting process is described, with consideration of the furnace temperature, lead bath temperature, and speed of passing through of the wire. Finally, some notes are given on the manufacture and treatment of high carbon wire for ropes and pianos.

Utilisation of Waste Heat for Drying Wire Bundles (Stahl und Eisen, Sept. 17, 1925, vol. 45, pp. 1605-1606). A newly designed installation for the drying of wire bundles after pickling is illustrated and described, in which the chambers are heated with the waste gases from pot annealing furnaces and with artificial air draft.

The Tinplate Industry.—H. Spence Thomas, *Presidential Address* (Proceedings of the South Wales Institute of Engineers, 1925, vol. 41, pp. 7-25). An interesting survey is given of the rise and development of the tinplate industry in South Wales. Several tables are included in the address giving details as to the output, costs, and materials used in the manufacture of tinplates at the Melingriffith Works one hundred years ago.

FURTHER TREATMENT OF IRON AND STEEL.

Cementation and Case-Hardening.—J. Laissus, *Cementation of Iron Alloys by Chromium* (Comptes Rendus, 1925, vol. 180, pp. 2040–2042). Experiments were made on steels of varying carbon content by packing them in powdered ferro-chrome containing 53 to 66 per cent. chromium and small amounts of carbon, and heating the whole to a high temperature. The following constituents were observed in the cemented alloy : an interior zone of solid solution in which the pearlite of the original steel had disappeared ; a eutectic zone ; and a bright external layer, consisting probably of a carbide of chromium formed above 1100°. When this latter compound is present the alloy is resistant to the action of nitric acid and to oxidation at high temperatures.

I. Fetchenko-Tchopivski, *Cementation of Iron, Nickel, and Cobalt by Boron* (Reports of the School of Mines, Cracow, 1925, No. 5, 44 pp.). The author describes experiments in the cementation of iron, nickel, and cobalt with pure boron. The materials used were normalised soft iron containing 0.075 per cent. carbon, a soft iron as received, with carbon 0.115 per cent., oxygen 0.197 per cent., and hypo-eutectic steel with carbon 0.4 per cent., a hyper-eutectic steel with carbon 0.95 per cent., nickel steels with 5 per cent. and 25 per cent. nickel, and ordinary nickel-chrome steels. These materials were annealed at temperatures from 900° to 1100° C. for periods of one to sixteen hours under various conditions. The conclusions were that boronising does not take place in atmospheric air ; that in an atmosphere containing carbon two processes proceeding on parallel lines are observable, the cementation with carbon and cementation with boron ; the boronising process proceeds with better results in an atmosphere of hydrogen, and with still better results in vacuum ; the first sign of successful boronisation is the appearance of borides (saturated solid solution of boron in α -iron) on the surface in the form of horseshoe nails ; the rapidity of diffusion of boron in iron and steel increases rapidly with the temperature. The ferro-borides formed on the surface are, however, so brittle and their adhesion to the core is so slight, that the entire eutectic, and frequently also the hypo-eutectic layer, flakes off at ordinary temperatures under the slightest mechanical stress. For the boronising of nickel, the atmospheric conditions remain the same as for iron, but the boronising begins at lower temperatures, and proceeds more rapidly in the case of nickel. The Report is printed in Polish with a summary in German.

C. H. S. Tupholme, *Influence of Containers in Case-Hardening* (American Machinist (European Edition), July 4, 1925, vol. 62, p. 158E). The type of container used, and the way it is packed, have decided effects on the case-hardening of the work contained in it. The author indicates some of the mistakes to be avoided and the best way of evading them.

A Nitrogen Process for Surface Hardening (Metallurgist, Sept. 25, 1925, pp. 140-141). Fry's new process of case-hardening by which the usual distortion of fine work is eliminated is described. Steel parts are heated in a gas consisting mainly of ammonia at a temperature not exceeding 580° C.; when a sufficient depth of case is obtained the parts are allowed to cool down in the furnace. The process is lengthy, lasting from forty to sixty hours. The case so produced is not brittle, as the temperature is not high enough for the formation of Fe_3N and Fe_4N and the iron-iron nitride eutectoid "Braunite," to the presence of which Dr. Fry attributes the brittleness ordinarily associated with nitrogen hardening.

B. F. Shepherd, *Carburising and Heat Treatment of Carburised Objects* (Transactions of the American Society for Steel Treating, June 1925, vol. 7, pp. 774-789). Recommendations for carburisation and heat treatment of carburised parts are given.

Avoids Softness in Carburising (Iron Trade Review, Aug. 6, 1925, vol. 77, pp. 308-310). Particulars are given of an investigation carried out by the Bureau of Standards on carburising of normal and abnormal steel. It is shown that by the use of salt-baths for the heating prior to quenching, soft spots on the specimens are prevented.

Carburising Practice (Iron Trade Review, July 2, 1925, vol. 77, pp. 5-7). The tentative recommended practice adopted by the American Society for Testing Materials for carburising and heat treatment of carburised objects is given in full.

Heat-Treatment Plant and Equipment.—W. Trinks, *Fuels and Furnaces for Heat Treating* (Transactions of the American Society for Steel Treating, July 1925, vol. 8, pp. 58-83). The author deals with gaseous, liquid, and solid fuels, in addition to electrical energy. The advantages and disadvantages of each fuel for heat treating are discussed. Methods of recuperation, preheating, and the compensating or counter-flow principle used for heat recovery are described. Methods of heat transfer, handling of materials through the furnace, and heat application are also dealt with.

C. L. Ipsen, *Determination of Furnace Efficiencies and Heat Treating Costs* (Transactions of the American Society for Steel Treating, July 1925, vol. 8, pp. 36-47). According to the author a statement of the efficiency of a furnace must be based on the operating cycle. The efficiency of an electric furnace may range from 33 to 78 per cent., depending on the cycle and the material to be treated.

J. W. Harsch, *Drawing by Convection* (Transactions of the American Society for Steel Treating, Sept. 1925, vol. 8, pp. 340-349). The

author describes an electric furnace for the tempering of hardened steel parts. Uniform temperature conditions are obtained throughout the furnace by the circulation of air from the source of heat to the work by means of a fan. The direction of circulation of the air is reversed at periodic intervals. The paper is illustrated with several heating curves, showing the temperature condition on the inside of the furnace when charged with different types of loads.

D. M. Gurney, *Equipment for Heat Treating Machine Tool Parts* (Transactions of the American Society for Steel Treating, July 1925, vol. 8, pp. 84-94). A description of the lay-out and equipment of plant for the heat treatment of lathe tools at an American works.

R. S. Sawdrey, *Electric-Furnace Installation* (Iron and Steel Engineer, 1924, vol. 1, pp. 487-489). Particulars are given of four box-type furnaces in operation at the Van Dorn Ironworks, Cleveland, Ohio. They are of the metallic resistor type with unmuffled heating elements on the side walls, and have automatic heat control. The furnaces are used for carburising, hardening, and tempering.

E. L. Shaner, *Heat Treating Key to Success* (Iron Trade Review, Sept. 17, 1925, vol. 77, pp. 680-683). An illustrated description of the heat-treating department for screws, bolts, and nuts of an American concern.

W. J. Walsh, *Replacing Oil with Electricity* (Iron Age, July 16, 1925, vol. 116, pp. 145-146). Illustrated particulars are given of the reconstruction of a heat-treatment furnace in order to install electric heating in place of oil-firing.

Punchings Require Careful Annealing (Iron Age, June 18, 1925, vol. 115, p. 1775). Brief particulars are given of the annealing furnaces used in an American works for the heat treatment of sheet steel punchings used in electric motors, generators, and transformer cores.

J. M. Layng, *Wire Mill Uses City Gas for Fuel* (Iron Age, July 30, 1925, vol. 116, pp. 275-278). An illustrated description is given of the heat-treating equipment of an American plant, where town gas is used by the surface combustion method for the heat treating of wire.

A New Regenerative Muffle (Metal Industry, July 24, 1925, vol. 27, pp. 74-75). A new annealing muffle heated by producer-gas is described. The gas is produced in a small producer attached to the muffle, and the air for combustion is heated on the regenerative system. The flames are caused to circulate above, round, and below the muffle in such a way as to keep the temperature even all through the muffle, and small dampers can be manipulated to correct any tendency towards unevenness. It is claimed that the muffle will work on a fuel consumption of 1 cwt. per ton of metal annealed.

H. Fulwider, *Electric Annealing of Steel* (Iron Age, Aug. 6, 1925, vol. 116, pp. 342-344). The advantages of electric heat treatment are discussed, and brief particulars are given of four types of furnaces in operation for ageing, normalising, and annealing of castings.

C. L. Ipsen, *Possibilities of Industrial Heating* (Iron Age, July 9,

1925, vol. 116, pp. 74-76). A discussion of the advantages of the electric furnace for the heat treatment and enamelling of metals.

Heat Treatment of Iron and Steel.—M. Kornatschewsky, *Conditions for the Regular Heat Treatment of High-Speed Steel* (Technical Section of Ukrainian Scientific Society : Stahl und Eisen, Sept. 10, 1925, vol. 45, pp. 1569-1570). The note describes the heat-treatment method for high-speed tool steel as carried out at the Putiloff Works at Petrograd in 1915. Two kinds of tungsten-chromium steels are considered, one cast, the other forged. The particulars of the treatment followed are described and shown in tables and diagrams.

C. B. Swander, *Heat Treatment of High-Speed Steel Dies* (Transactions of the American Society for Steel Treating, June 1925, vol. 7, pp. 727-734). The author describes a method for hardening high-speed steel dies. The work is heated in tightly sealed graphite crucibles, with a small amount of silica sand and charcoal in the bottom. The dimensional changes of work hardened by this method were also studied.

G. Bergstrom and L. Nordenfelt, *Selection and Treatment of Drill Steel* (Paper read before the Chemical, Metallurgical, and Mining Society of South Africa : Iron and Coal Trades Review, Oct. 2, 1925, vol. 111, pp. 522-523). The subject is dealt with by the authors mainly from the point of view of experience gained in the mines of the Rand. Useful data are given regarding drill steel and its quality, heat treatment and uses in mining practice.

Steel for Rock-Drills (Stahl und Eisen, June 18, 1925, vol. 45, pp. 992-995). A review is presented of four papers published in different sources within the last four years on the subject of the manufacture of hollow drill steel, its most suitable composition and treatment. Plain carbon steel gives as good results as any alloy steels. Great difficulties exist in the way of keeping precise records of the life and serviceability of rock-drills, owing to differences in the kind of rock they are used upon and in the method of their use.

The Magnetic Indicator and Steel Hardening (Machinery, June 18, 1925, vol. 26, p. 380). The article refers to the use of the Wild-Barfield furnace which is fitted with an indicator showing the magnetic condition of the work under treatment. Two heats were carried out under test conditions on a 1.4 per cent. carbon steel. In the first case the furnace temperature was 750° C. and the metal lost all trace of magnetism in twenty-seven minutes, while in the second case the furnace temperature was 880° C. and the metal became completely non-magnetic in 7½ minutes. The temperature of the first batch of metal when completely demagnetised was, as shown by a thermocouple in a cavity in the steel, 730° C., but in the second case it was 760° C. For practical purposes in the case of carbon steels and certain other steels, the non-magnetic condition coincides with the correct condition for quenching, so the magnetic indicator enables the hardener to

quench at the correct moment without fear of soft spots or overheating, regardless of the conditions imposed by variations in the work and furnace.

A. Pomp, *Influence of Heat Treatment on Notch Toughness of Chain Material* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1180-1184). Since the introduction of the electric welding machine the substitution of mild steel (0.10 per cent. carbon) for wrought iron has become established practice. A series of comparative notched-bar tests has been made to determine the notch toughness of chain-making material at temperatures ranging from -70° to $+100^{\circ}$ C. Three materials were chosen for the tests as follows :

	C.	Si.	P.	S.	Mn.
Wrought iron (per cent.)	0.03	0.065	0.19	0.013	0.15
Mild steel (,, ,)	0.10	0.04	0.008	0.014	0.47
Special soft steel (,, ,)	0.06	0.014	0.004	0.023	0.15

The first two materials were from the Gutehoffnungshütte, the third was from Krupp's. The main results of notch-bar tests after different kinds of treatment are shown in the following tables :

Wrought Iron.

At Degrees C.	Kgm. per Square Centimetre.		
	As Rolled.	Annealed Two Hours at 920° C.	Cold-Worked to 10 per Cent. Reduction of Area.
-70	0.2	0.75	0.75
-40	1.9	1.0	1.25
-20	4.0	3.0	2.0
0	8.5	3.5	2.0
20	12.5	5.5	12.5
50	13.0	7.0	14.0
100	11.0	10.0	16.5

Mild Steel.

At Degrees C.	Kgm. per Square Centimetre.			
	As Rolled.	Annealed Two Hours at 920° C.	Cold-Worked to 10 per Cent. Reduction of Area.	Quenched and Tempered.
-70	2.0	0.5	0.5	1.5
-40	2.0	1.0	1.0	1.5
-20	2.5	1.5	2.0	3.0
0	5.0	2.0	26.0	46.5
20	43.0	4.5	33.0	48.0
50	37.5	32.0	32.5	51.0
100	42.0	35.0	33.0	54.0

Special Soft Steel.

At Degrees C.	Kgm. per Square Centimetre.			
	As Rolled.	Annealed Two Hours at 920° C.	Cold-Worked to 10 per Cent. Reduction of Area.	Quenched and Tempered.
— 70	2.0	0.5	0	2
— 40	1.75	1.0	1	39
— 20	3.5	2.0	2	43
0	37.0	4.0	26	44
20	37.5	19.0	37	48
50	40.0	36.0	37	48
100	37.0	38.0	34	47

The figures are chiefly of interest in showing the great improvement in toughness due to heat treatment, especially quenching (from 920°) and tempering (at 650°). The wrought iron specimens were not subjected to this latter treatment.

F. A. Livermore, *The Heat Treatment of Gauge Steel* (Automobile Engineer, May 1925, vol. 15, pp. 142-143). The alterations of volume that take place during alternate heating and cooling of gauge steels are of supreme importance, since material subject to critical volume changes is unsuitable for gauges. The author describes experiments carried out to investigate these volume changes, and after giving sketches of the special furnace used, he sets out his results obtained on the following steel: sulphur, 0.034 per cent.; silicon, 0.15 per cent.; phosphorus, 0.019 per cent.; carbon, 1.05 per cent.; manganese, 0.95 per cent. The curves of the critical points were first plotted, and from these it was decided that the sample tools should be hardened at 750° C. A definite increase in volume resulted and experiments were made to find the best rate of cooling and the best quenching medium, and the correct temperature at which to maintain it. Best results were obtained with whale oil at 25° C. Tempering temperatures were next examined, and specimens heated to 260° C. and tempered in whale oil were the most satisfactory. This reheating was accompanied by a contraction, and, in a table given, the author shows that this treatment causes the finished article to return to its original size within a very small decimal range.

Recommended Practice for the Heat Treatment of Taps and Milling-Cutters (American Machinist (European Edition), Sept. 5, 1925, vol. 63, p. 194). This is a tentative recommended practice approved by the Recommended Practice Committee of the A.S.S.T. It is to be followed in the treatment of taps and milling-cutters made from plain carbon tool steel, 18 per cent. tungsten high-speed tool steel, and 1.5-2.0 per cent. tungsten tool steel only, and is not to be applied to taps and milling-cutters having other chemical compositions than those given in the article.

Some Metallurgical Considerations of Gears (Machinery, Apr. 16, May 21, 1925, vol. 26, pp. 77-81, 241-244). The manufacture of gear wheels and the choice of alloy steel to be used is discussed from the metallurgical standpoint. Temper brittleness and the freedom of nickel-chrome-molybdenum steel from this defect is considered. Heat treatment, machinability, and causes of failure are touched upon. A few words are added on the subject of cast iron and non-ferrous alloys for gears.

J. W. Urquhart, *Machinery Steels and Heat Treatment* (Machinery, Oct. 8, 1925, vol. 27, pp. 52-53). The author deplores the fact that many manufacturers of machinery are using alloy steels in many cases where a plain carbon steel would be equally efficient. In the untreated condition alloy steels such as a 2.5 per cent. nickel, 1.7 per cent. chromium steel, have no advantages over a 0.4 per cent. carbon steel, and in order to bring out the properties of the alloy steels heat treatment is necessary and this process must be performed correctly. The author gives an explanation of the superior heat treatment results that are obtainable with the alloy steels, but offsets these with the additional cost involved and the fact that frequently these superfine steels are unnecessary for the machine to be built. The author indicates the manner in which plain carbon steels can be treated in order to make them in every way suitable for machinery construction. It not infrequently happens that the extra mass needed to provide sufficient strength in a machine built of carbon steel is an advantage because the extra weight makes for greater stability, especially in fast-running machines.

C. S. Smith, *Heat Treatment of Steel Dies* (Iron Age, Sept. 3, 1925, vol. 116, pp. 608-610). Practical methods are described of oil-hardening non-shrinkable steels and water-hardening steels.

A. N. Conarroe, *The Heat Treatment of Steel Castings* (Transactions of the American Society for Steel Treating, Aug. 1925, vol. 8, pp. 150-162). The author describes the heat treatment of steel castings, including annealing, normalising, quenching and tempering, and case-hardening. A brief discussion of melting practice, and the defects and impurities found in steel is included.

W. J. Merten, *The Metallurgical Engineering of Aircraft Propeller Hubs* (Transactions of the American Society for Steel Treating, June 1925, vol. 7, pp. 718-726). The author describes research work carried out in order to ascertain the correct design and heat treatment for the successful production of aircraft propeller hubs. A comparison of the characteristics and properties of chromium-vanadium steel heat-treated in the forged and rolled conditions is given.

E. A. Wright, *Failures in Steel Components* (Mining Journal, May 16, 23, 1925, vol. 149, pp. 397, 420-421). A great many failures in steel components, apart from those due to faulty design, can be attributed to bad heat treatment. The author enumerates and gives examples of some of the many ways in which improper heat treatment

has caused failure, as proved by mechanical tests and micro-examinations made after the breakdown. Another fruitful cause of trouble is the use of a steel unsuited to the task it has to perform.

H. B. Knowlton, *Facts and Principles Concerning Steel and Heat Treatment* (Transactions of the American Society for Steel Treating, June 1925, vol. 7, pp. 743-773). The author explains the changes in structure and properties produced by cooling plain carbon steel at different rates from above the critical point. The process of tempering or drawing is also outlined.

C. B. Bellis, *Contemporary Heat Treating Practice* (Transactions of the American Society for Steel Treating, Aug. 1925, vol. 8, pp. 241-249). A brief description of some methods of hardening and carburising tools and steel parts.

P. Winchell, *The Story of Steel Treating* (Iron Age, Sept. 3, 1925, vol. 116, pp. 593-604). The author traces the development of the science of metallography of steel, and the parts played by the leading investigators.

J. W. Donaldson, *Low-Temperature Heat Treatment of Special Cast Irons* (Paper read before the Institution of British Foundrymen: Foundry Trade Journal, June 18, 1925, vol. 31, pp. 517-522). The author gives the results of experiments on the effects of low-temperature heat treatment and the additions of special elements on cast iron. The influence of manganese, chromium, nickel, tungsten, vanadium, and the combined effects of chromium and nickel are dealt with. The conclusions derived from the various tests are as follows:

Annealing cast iron for prolonged periods at temperatures of 450° C. and 550° C. respectively produced changes in the composition of the iron which affect the strength and hardness of the material. These changes are due to decomposition of the carbide, and are more marked at the higher temperature. If cast iron is to be subjected to elevated temperatures, its strength at those temperatures cannot be determined on cast bars. The material has to be annealed at the working temperature until the carbide change is complete before making tests. Cast iron, if of suitable composition, will show very little growth or change of volume after repeated heatings and coolings. Small additions of special elements modify the properties of cast iron, both as regards annealing and strength at elevated temperatures as well as the growth properties. The addition of chromium to the extent of 0.4 per cent. modifies the properties of the iron to the greatest extent. The initial strength is increased by 11 per cent., the carbide is rendered more stable on annealing, with a corresponding smaller reduction in the strength and hardness; and the breaking strength at 400° C., after stability is attained with prolonged annealing, is 25 per cent. greater than that obtained with a corresponding iron containing no chromium. Repeated heatings and coolings to 550° C. produce a small decrease in volume instead of growth. Increasing the manganese from 1.0 per cent. to 2.5 per cent., or adding 0.5 per cent. of tungsten, produces results

somewhat similar to each other and similar to those produced by the chromium, but by no means so marked. The growth of both irons is small, that with the tungsten being practically nil. Adding 0.75 per cent. of nickel or 0.125 per cent. of vanadium slightly improves the initial strength of iron, but renders the carbide less stable during annealing, a large amount of graphitisation taking place even at 450° C., with a corresponding large decrease in the strength and hardness. The effect of adding both chromium and nickel in the proportion of 2 and 1 allows the use of a higher percentage of chromium, although it would appear that the benefits derived from the increased chromium as regards stability of the carbide and strength at elevated temperatures are more than diminished by the accompanying nickel. Better results would no doubt be obtained by omitting the nickel and increasing the chromium with additional silicon.

C. H. S. Tupholme, *Welded Joints in Cast Iron Pipe* (Foundry Trade Journal, May 28, 1925, vol. 31, pp. 458-459). The application of bronze welding to cast iron pipe is discussed, and the results of tests showing the flexibility of bronze-welded pipe are tabulated. Particulars are also given of the quantity of bronze and flux required for welding pipes of various diameters.

F. Grotts, *Heat Treatment of Cast Iron* (Transactions of the American Society for Steel Treating, June 1925, vol. 7, pp. 735-742). A discussion of the physical properties of cast iron and the modifications obtained by heat treatment.

Heat Treatment not Always at Fault (Machinery, July 30, 1925, vol. 26, p. 559). A short article pointing out that failure of tools is not invariably the result of bad heat treatment, but that choice of wrong materials and other points can have an equally serious ill-effect. Ill-usage of the tools is a not infrequent cause of trouble.

K. B. Millett, *Some Methods for Cooling Quenching Oil* (Forging, Stamping, Heat Treating, July 1925, vol. 11, pp. 232-234).

H. C. Knerr, *Heat Treatment and Metallography of Steel* (Forging, Stamping, Heat Treating, Oct., Nov., Dec. 1924, vol. 10, pp. 385-392, 419-430, 459-466; Jan. to Aug. 1925, vol. 11, pp. 18-23, 54-62, 95-102, 125-132, 166-171, 194-201, 243-249, 264-267, and 283). This serial forms a practical course in the elements of the physical metallurgy of iron and steel, and describes all the operations involved from the smelting of the ore in the blast-furnace to the manufacture of steel and the treatment of the finished products.

Improved Method of Sawing Rails.—F. L. MacQuarrie, *Better Ends for Rails* (Iron Age, Aug. 6, 1925, vol. 116, pp. 346-347). The author briefly discusses methods of eliminating the burred edge of steel rails caused by hot sawing. The section cut by the saw during its course through the rail is broken up into small particles or sparks in a fused state. These particles are hurled on to the surface of the rail and are partially welded and fused together, forming almost a solid cake. This is very difficult to remove by machining or chipping, and its presence

is an objectional feature in fitting fish plates. Two water-jets, one on each side of the saw, will entirely eliminate this defect, and will not chill the rail.

Manufacture of Steel Balls for Bearings.—H. G. Freeland, *Relationship of Ball Quality to Bearing Life* (Transactions of the American Society for Steel Treating, Sept. 1925, vol. 8, pp. 309-323). The author briefly describes some of the important fundamentals governing the design, manufacture, and application of ball bearings.

Welding and Cutting.—P. L. Roberts, *The Mechanical Properties of Resistance-Welded Joints* (Machinery, June, 18, 1925, vol. 26, pp. 366-369). The author outlines briefly the process of resistance welding and adds a note on the faulty results which will occur if the current density and controlling apparatus are badly adjusted. One of the greatest influences on the mechanical strength is the alteration of the microstructure of the weld and the surrounding metal; there should be a gradual transition from one type of structure to the other and any sudden change leads to weakness. Tables are given showing results of tests on typical welds, and two tables show a comparison of the cost of arc welding and oxy-acetylene welding. In this connection the cost of power for arc welding was calculated at "a penny per B.O.T. unit" and not, as stated, "a penny per B.Th.U."

Electric Welding (Machinery, 1925, vol. 26, June 18, 25, July 2, 9, 16, pp. 353-365, 385-393, 417-425, 457-459, 489-495). A review of recent developments in the design and use of electric welding equipment. The comparative advantages of arc and resistance welding are that the plant for the former is more portable, but the latter process is cheaper, especially on repetition work. The articles, which are well illustrated, deal with resistance welding in great detail and include information on the general principles of welding, metals that can be welded, electric brazing, spot welding, with particular reference to chain making, butt welding and its application to joining wires, seam welding, and local heating, such as is required for rivet heating and pipe bending. The last article is concerned with arc welding.

W. L. Warner, *Notes on Welding and Cutting by Carbon Arc* (Chemical and Metallurgical Engineering, May 1925, vol. 32, p. 517). The author gives a general outline of the procedure in cutting and welding by means of an electric arc, using a graphite or carbon electrode. The length of arc and best variety of electrode for both cutting and welding are indicated, the best conditions for obtaining sound welds and the kind of filling material to use are noted, and the precautions to obviate hard welds and leave the joint in a condition for machining, despite the use of the carbon electrode, are given.

W. L. Warner, *An Electrically Welded Barge* (General Electric Review, Jan. 1925, vol. 28, pp. 66-70). The first completely arc-welded vessel constructed in America was launched in December 1924. It is

an oil-barge 76 feet long, 21 feet in the beam, and the deck is 11 feet above the keel. The hull consists of $\frac{3}{16}$ -inch plates joined by two fillet lap welds and the ribs are spaced 22 inches apart and are tack welded on both toe and heel sides by 4-inch tack welds 8 inches apart. The barge is built round two cylindrical tanks having a combined capacity of 52,000 gallons of oil. Details of the construction and welding are given. The cost of construction is considerably less than for riveting, owing mainly to the reduction in the number of workmen necessary, six men being employed where eighteen would otherwise have been required.

Electric Arc Welding for Shipbuilding (Electrician, Aug. 7, 1925, vol. 95, pp. 146-147). Abstract of a paper by Strelow read before the Schiffbautechnische Gesellschaft in Berlin. The author emphasises that the replacement of riveted joints by arc-welded joints is a very likely probability of the near future, for two reasons: first, arc welding is cheaper than riveting, because there is not the need for the same amount of preparatory and finishing work; secondly, it is possible to make a joint with 100 per cent. efficiency by welding, whereas a normal riveted joint is only about 70 per cent. efficient. A brief description is given of the method of working and also a sketch plan of a special low-tension dynamo for supplying large currents at low potentials with special controlling switch-gear. The practical application of arc welding to shipbuilding requires special methods of construction, and one process devised by the author is described.

Building Machines by Welding (Machinery, June 18, 1925, vol. 26, pp. 371-373). Descriptions are given of various machines built up of plates welded together instead of castings.

J. M. Vossler, *Repairing Locomotive Frames by Arc Welding* (American Machinist (European Edition), Aug. 29, 1925, vol. 63, pp. 151-154). Details are given of the application of arc welding, using the metallic arc, to the repair of locomotive frames.

E. F. Ross, *Applies Electric Arc to Production Work* (Iron Trade Review, July 16, 1925, vol. 77, pp. 125-128, 138). The practice of the Lincoln Electric Co., Cleveland, in the use of electric welding for the assembly of electric motor parts and welding apparatus is described and illustrated.

Welded Valves (Automobile Engineer, Aug. 1925, vol. 15, p. 272). A short description is given of the method of manufacture adopted by the Taylor-Hall Welding Corporation, U.S.A., for making valves for internal combustion engines. Cast iron heads are welded to steel stems in such a way that the welded joint is stronger than the stem itself.

R. L. Scollard, *Arc Welding in Steel Mills* (Blast-Furnace and Steel Plant, July 1925, vol. 13, pp. 298-299). The arc-welder is becoming more and more necessary in the works as a means of dealing with an emergency or other breakdown. Photographs are reproduced indicating some of the types of repairs that can be made to worn or broken parts.

W. R. Needham, *Welding—the Filling-in and Putting-on Tool* (Electrical Review, June 19, 1925, vol. 96, pp. 967–969). A review of the purposes and uses to which welding may be put. Several references are given.

C. H. S. Tupholme, *Welding Copper to Steel by Electricity* (Electrical Review, May 8, 1925, vol. 96, p. 731). Considerable progress has been made in the welding of copper to steel as in the connection of copper leads to steel rails. The weld nowadays is made in a mould and the welding material is a copper-silicon alloy, the silicon being a powerful deoxidizer and so producing a weld of good electrical conductivity. The copper-silicon alloy has an average shearing strength of 30,000 lbs. per square inch. Two methods of working are in use depending on whether a copper or a carbon electrode is used.

F. Sauerwald, *The Phenomena in Press Welding and a Method for their Investigation* (Stahl und Eisen, July 23, 1925, vol. 45, pp. 1274–1276). Iron in the form of powder was heated and welded under pressures of 3600 and 1500 atmospheres and at zero pressure. The welding temperatures were 900°, 1100°, and 1300° C. The resulting crystallite conglomerates were tested for their tensile strength, which was found mainly to be influenced by the welding temperature, but also very largely by the pressure exerted. Pure powdered metals can always be welded, provided the crystallite surfaces are clean.

F. Politz, *The Fusion Welding of Grey Cast Iron by Acetylene* (Stahl und Eisen, Apr. 30, 1925, vol. 45, pp. 653–658). The thermal effects of welding cast iron by fusion of the surfaces with the acetylene flame are considered. Satisfactory welds can be made without preheating the whole pieces; the stresses are not too great and the weld is machinable. On the other hand, welding after preheating to 900° C. has great advantages, and risk of failure is reduced to a minimum, also the tensile strength of the weld is higher than in welding without preheating. In cold welding the structure of the weld was fine grained and contained ledeburite, but in hot welding it consisted only of pearlite and graphite. In the latter case the weld was softer and withstood a breaking load 50 per cent. greater. Excess of oxygen or acetylene, long heating or overheating deteriorated the weld.

Effect of Oxygen-Cutting on Steel (Machinery, June 4, 1925, vol. 26, p. 296). Brief details of the results of experiments performed by the Union Carbide and Carbon Research Laboratories are given indicating that any deterioration caused by the oxygen-cutting of steel is confined to a quite negligible depth below the surface.

Cutting Cast Iron and Copper Alloys by the Electric Arc Process (Machinery, July 2, 1925, vol. 26, pp. 430–431). The use of the electric arc in the scrap yard for reducing large castings to a convenient size for the furnace is described.

Pickling.—Brenier, *Effects of Acid Pickling on the Tubes of Belleville Boilers* (Revue de Métallurgie, Mémoires, Sept. 1925, vol. 22, pp. 568–1925—ii.

570). A number of Belleville tubes which had been allowed to become rusty during storage were placed in a weak acid bath in order to remove the rust. In these conditions every one of the tubes cracked. A fresh batch, submitted to a similar operation, behaved in the same manner. The fault was attributed to corrosion cracking, but a series of notch-bar tests on pickled and unpickled tubes revealed no difference in regard to brittleness between them. Also it was found that, even in the case of pickling, defects could be prevented by a careful annealing of the tubes before placing them in the bath of acid.

PHYSICAL AND CHEMICAL PROPERTIES.

Properties and Tests of Cast Iron.—H. A. Schwartz, *Determination of the Density of Liquid Cast Iron* (Industrial and Engineering Chemistry, June 1925, vol. 17, pp. 647–648). A simple method is described for determining the density of liquid cast iron. Within the limits of 1375° and 1500° the coefficient of expansion of liquid iron is constant.

D. Saito and K. Hayashi, *On the Fluidity of Metals and Alloys* (Memoirs of the College of Engineering, Kyoto Imperial University, July 1924, vol. 3, pp. 165–178). The authors describe methods for determining the fluidity of metals, and give the results of experiments on the influence of phosphorus on the fluidity of cast iron.

P. Bardenheuer and C. Ebbefeld, *An Examination of the Shrinkage Process in White and Grey Cast Iron* (Stahl und Eisen, May 28, June 25, 1925, vol. 45, pp. 825–834, 1022–1026). The results of this investigation have been previously published (Mitteilungen a.d. Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 6, Part 6, pp. 45–60; Journal of the Iron and Steel Institute, 1925, No. I. p. 502).

I. Jaederstroem, *The Influence of Various Elements on the Shrinkage of Cast Iron and Steel* (Testing, 1924, vol. 1, pp. 290–307). The influence of carbon, silicon, manganese, phosphorus, sulphur, nickel, and chromium on the shrinkage of cast iron and steel was determined. Shrinkage and cooling, and expansion and contraction curves are shown.

The Influence of Rate of Cooling and Casting Temperature on Cast Iron (Foundry Trade Journal, Oct. 1, 1925, vol. 32, pp. 275–279). A summary of the work of various investigators.

E. R. Taylor, *The Effect of Sulphur on the Mechanical Properties of Whiteheart Malleable Cast Iron* (Iron and Steel Institute, Carnegie Scholarship Memoirs, 1925, vol. 14, pp. 131–161). The material used for the test-bars was a hæmatite white iron with 0·65 per cent. sulphur; for test-bars containing a lower percentage of sulphur this metal was diluted with pure Swedish white iron; and for test-bars of higher sulphur an addition of ferrous-sulphide was made. The test-bars of standard size were cast with sulphur ranging from 0·015 per cent. to 1·496 per cent. The bars were annealed in hæmatite or in a manner representing general works practice. Tensile tests demonstrate the effect of increasing percentages of sulphur, the tensile strength beginning to fall from 0·1 per cent. sulphur and diminishing consistently from 24 tons to 8 tons per square inch, the degrees in loss of strength being

greatly accelerated after passing 0.4 per cent. sulphur. The bend tests showed the same characteristic.

J. H. Andrew and R. Higgins, *The Dilatation of Cast Irons during Repeated Heating and Cooling* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 167-185).

P. Oberhoffer and E. Piwowarsky, *The Growth of Grey Iron* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1173-1178). A critical examination of the work of previous investigators of the phenomenon associated with the growth of cast iron is presented, with an account of experiments made with the object of confirming or otherwise the observations of others. Dilatation curves are given illustrating the behaviour of grey and white cast iron as the result of repeated heating and cooling.

J. E. Hurst, *The Heat Treatment and Volume Changes of Grey Cast Iron* (Foundry Trade Journal, July 16, 1925, vol. 32, pp. 49-52). The subject is discussed under the following headings: Constitutional changes on heating cast iron; decomposition of carbides by heat treatment; microstructure of heat-treated cast iron; influence of heat treatment on the strength properties; low-temperature heat treatment; volume changes and growth; volume changes at low temperatures and the influence of thermal expansion.

H. O'Neill, *The Breuil Volume-Meter and the Density of Metals* (Metallurgist, July 31, 1925, pp. 105-106). The apparatus (illustrated) was designed to determine the volume of weighed samples of wood, and consequently their density. It consists of a steel reservoir 32 millimetres internal diameter and 50 millimetres high, closed at the top by a screw cap carrying an open glass capillary index tube. Within a steel cylinder fixed to the side of the reservoir is a piston mounted on a micrometer screw. The cross-section of the cylinder is such that the smallest division on the micrometer drum corresponds to a change in volume of 3 cubic millimetres of the enclosed chamber; finer reading is possible by estimation. Mercury is used as the containing liquid, and is forced up the index tube to a pointer by means of the piston. The difference between the readings obtained when empty and then with a specimen immersed in the chamber indicates the volume of the specimen.

For metallurgical work mercury as a containing liquid has disadvantages: it amalgamates with many metals, and its surface tension does not allow it to wet the whole surface of wrinkled metal specimens. Other liquids have been tried, but they all leak out, whereas mercury does not, so that at present it is the only liquid available. The volume of a smooth polished specimen of ferrous alloy having a volume of about 5 cubic centimetres may be determined in the instrument with an error of not more than ± 0.1 per cent. In suitable specimens blowholes and overdrawing cavities could readily be detected by the use of this instrument.

R. Kühnel, *The Structure of High Quality Grey Cast Iron in Relation to Chemical Composition and to the Mechanical Properties* (Stahl und Eisen, Aug. 27, 1925, vol. 45, pp. 1461-1466). The results of numerous

tests plotted in curves show in the case of high quality castings for cylinders and valve boxes that hardness and tensile strength have no fixed relation to each other, but that the relation is largely influenced by the rate of cooling. The bending strength also fluctuates considerably as the tensile strength rises. A communication by Schüz to the discussion of pearlitic cast iron expresses the view that in a purely pearlitic iron with not too much phosphide eutectic, having tensile strengths over 24 kilogrammes per square millimetre, the hardness does not vary much, while the strength increases, due to the finer distribution of the graphite lamellæ. If the phosphide eutectic increases until the cast iron becomes hyper-pearlitic, the hardness increases and the tensile strength drops. Of the various methods of testing, the bending test gives somewhat uncertain results, but tensile and hardness tests supplement each other. For non-pearlitic iron hardness is a much surer test than the tensile, and is closely related to resistance to wear and to the structure.

O. W. Potter, *The Effect of Heat Treatment on the Properties and Microstructures of Grey Cast Iron and Semi-Steel* (Paper read before the American Foundrymen's Association, Oct. 1925). The authors have investigated the factors involved in the correct heat treatment of cast iron and semi-steel. Proper heat treatment can greatly improve the general properties. One of the most important results is a uniform hardness and the elimination of massive cementite under annealing. A formula is given for calculating the critical temperature of grey cast iron and semi-steel from the chemical analysis.

H. J. Young, *A Note on the Practice and Purpose of Perlit Iron* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, June 11, 1925, vol. 31, pp. 503-506). A brief discussion of the mechanism of the Perlit cast iron process. The author shows that when following this process there appears a "hesitation" of a much greater magnitude than when pursuing normal methods. This conception enables one to appreciate that much may happen to explain the absence of core and the presence of an all-pearlitic structure throughout an intricate casting made in this manner.

Pearlite in Cast Iron (Metal Industry, Aug. 28, Sept. 4, Oct. 2, 1925, vol. 27, pp. 189-192, 219-221, 315-318). The general structure and appearance of pearlite, the various forms in which it occurs and its relation to other micro-constituents with which it may be associated are discussed. Slight variations in chemical composition, or in physical, particularly thermal, conditions may have a very great influence on structure, and even differences in mode of distribution can have a very marked effect. The article is illustrated with numerous micrographs.

Pearlitic Cast Iron (Machinery, June 4, 1925, vol. 26, p. 299). A very brief note on a further development of the production of cast iron of pearlitic structure by the Lanz process, by the use of nickel-chromium and other elements generally used in refining steel.

A. Lissner and R. Horny, *Temper Carbon and Graphitic Carbon Considered as Chemically Similar Forms of Carbon* (Stahl und Eisen, July 30, 1925, vol. 45, pp. 1297-1301). By careful preparation of pure pig iron graphite and pure temper carbon the possibility has been established of determining the more important properties of these two kinds of carbon. It is proved that they react in exactly the same manner to chemical agents such as nitric acid, concentrated nitric acid, and sulphuric acid, nitric acid and potassium chlorate and melting sulphate of soda. In particular, both forms of carbon are transformed with the same speed into almost identical graphitic acids. The combustion temperatures are practically the same, but on the other hand the temper carbon reacts more readily to oxygen (the temperature of ignition being lower) and also to iron above 800° C. (for example, in cementation tests). The cause of this greater capacity for reaction in the case of temper carbon is due to the extremely finely divided state of this form of carbon.

J. T. Mackenzie, *The Influence of Phosphorus on the Total Carbon Content of Cast Iron* (Paper read before the American Foundrymen's Association, Oct. 1925).

J. R. Eckman and L. Jordan, *The Oxygen Content of Coke and Charcoal Cast Irons* (Paper read before the American Foundrymen's Association, Oct. 1925). Charcoal cast irons are, in general, appreciably stronger than coke cast irons of the same composition and melted under identical conditions. This has been attributed by some investigators to a higher oxygen content in the stronger irons. The results of analyses, carried out by the author, of charcoal and coke irons of known mechanical properties, failed to support the conclusion as to the strengthening effect of oxygen on the mechanical properties of grey cast iron. The method of analysis used in the investigation was the Bureau of Standards vacuum fusion method, which is stated to be more accurate for the determination of oxygen, as applied to cast iron, than other methods employed.

T. H. Wickenden and J. S. Vanick, *Nickel and Nickel-Chromium in Cast Iron* (Paper read before the American Foundrymen's Association, Oct. 1925). The authors have carried out an investigation of the influence of nickel and nickel-chromium additions on the properties of grey cast iron. The results of the investigation are described and the commercial applications of nickel and nickel-chromium cast irons are discussed. Three grades of iron were used in the experiments, carrying 1.4, 2.00, and 2.70 per cent. of silicon together with low sulphur and phosphorus. The nickel content was varied up to 5 per cent., the chromium content up to 1 per cent., and the two alloy additions were made both singly and in various combinations. Nickel accelerates graphite formation and carbide decomposition, and is very effective in reducing chill. Chromium additions always tend to increase chill, but this effect is restrained by the presence of nickel, except that small additions of nickel (0.25 per cent. or less) appear to intensify the

chilling effect of small amounts of chromium. Nickel and chromium of relatively small amounts, alone or in combination, both serve to refine the grain of grey iron. With large additions of nickel, 5 to 10 per cent., the grain is coarsened. Chromium additions increase the hardness by increasing the combined carbon. Nickel additions from 0.25 to 5 per cent. increase the hardness without impairing machinability. The development of increased strength requires different amounts and ratios of the alloying elements for different compositions of iron and for different sections of castings. To increase strength from 10 to 50 per cent. requires 0.5 to 1.00 per cent. of nickel together with 0 to 0.50 per cent. of chromium, depending on the grade of iron—a high silicon iron requiring a greater addition of chromium.

J. Ward, *Hardness Governs Machinability* (Foundry, Sept. 1, 1925, vol. 53, pp. 684–687). The author discusses some of the factors influencing the machinability of cast iron. There are two types of hardness which affect machinability, namely, strength hardness as measured by the Brinell test, and abrasive hardness.

Factors Influencing the Machinability of Cast Iron (Machinery, July 16, 1925, vol. 26, pp. 499–501). The idea that graphite causes wear on machine tools is proved to be wrong, the graphite making the mass of metal weaker but not increasing its abrasive action. The machinability of white and mottled irons is affected by the presence of cementite, iron carbide, which is very hard and brittle. In the case of grey cast irons the abrasion is due to steadite, a very hard phosphorus-rich compound.

C. Dickinson, *Testing of Cast Iron* (Lecture before the Sheffield Foundry Trade Technical Society: Foundry Trade Journal, July 9, 1925, vol. 32, p. 40).

A. Levi, *Heat-Resisting Cast Iron* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, June 25, 1925, vol. 31, pp. 549–554). The author reviews the work of previous investigators on the influence of temperature on the physical properties of cast iron, and submits a number of compositions suitable for different types of castings which have to withstand the action of heat.

J. E. Hurst, *The Mechanical and Physical Properties of Cast Iron* (Foundry Trade Journal, June 25, July 9, 30, Aug. 6, 1925, vol. 31, pp. 545–548, vol. 32, pp. 31–32, 101–105, 118–120).

Properties and Tests of Wrought Iron and Steel.—*Wrought Iron or Steel* (Engineer, June 12, 1925, vol. 139, p. 656). There are still a number of special purposes for which wrought iron is preferred to steel, and the special features claimed for it are resistance to shock, resistance to corrosion, and ease of welding. The point is debated whether modern steels have not been so perfected as to be able to replace wrought iron with a material equal if not superior to it in these very respects, and with the added advantage of amenability to heat treatment.

S. A. Richardson, *Cooling Cause of Brittleness* (Iron Trade Review, Sept. 3, 1925, vol. 77, pp. 550-552, 568). The author has studied the relation between the initial structure of steel castings and their brittleness. Annealed or untreated steel castings, whose initial cooling was slow, tend to have the pearlite in uniformly distributed masses, which promote greater ductility and resistance to shock. To avoid brittle-castings of moderate size should be allowed to cool in the mould.

C. B. Sawyer, *The Reactions and Effects of Nitrogen on Steel* (Transactions of the American Society for Steel Treating, Sept. 1925, vol. 8, pp. 291-308). A review of a number of important papers dealing with nitrogen in steel.

L. Guillet and A. Portevin, *Influence of Quenching on the Mechanical Properties after Tempering* (Revue de Métallurgie, Mémoires, Jan. 1925, vol. 22, pp. 52-56). In the experiments recorded the variations in the conditions of cooling were brought about by varying the diameters of the bars quenched while preserving the quenching conditions otherwise constant. The steels were medium carbon qualities and a range of nickel-chromium steels. With air-hardened and rustless nickel-chromium steels the hardness after quenching and the impact resistance after tempering were too low to determine the effect; the differences were within the limits of experimental error, and in all cases the samples were martensitic after quenching and sorbitic after tempering. With semi-hard nickel-chromium steels and case-hardened steels the same structures were observed. In the case, however, of carbon steels, those water-quenched were martensitic throughout, but in oil-quenched samples troostite and traces of ferrite were found, while samples quenched in boiling salt-water solutions showed a ferrite network accompanied by troostite. So far as the results justify drawing conclusions it was found that, with similar degrees of hardness after tempering, the impact-resistance is better in samples completely hardened—that is to say, consisting of pure martensite—and, conversely, with similar impact-resistance after tempering the ultimate hardness is higher in proportion as the quenching has been more energetic.

A. Kattô, *On the Effect of Repeated Quenching on the Hardness of Carbon Steels* (Science Reports of the Tôhoku Imperial University, 1924, vol. 13, pp. 373-383). A 0.88 per cent. carbon steel was used in the experiments. The hardness after repeated quenchings was measured with the scleroscope and magnetically. The hardness-quenching temperature curves for mechanical and magnetic hardness are similar, and nearly coincide above 760°. A forged specimen, quenched repeatedly at 750°, showed maximum hardness at the second quenching. Preliminary heating did not improve the results from the first quenching. Magnetic tests showed that in the forged specimen the cementite was partially decomposed. The effective carbon content therefore was low, and a higher temperature was required for hardening until by the first heat treatment the normal amount of cementite was formed

again. Other quenching experiments also indicated that imperfect hardening in oil may be due to the carbon remaining insoluble at a comparatively low quenching temperature.

H. J. French and O. Z. Klopsch, *Initial Temperature and Mass Effects in Quenching* (United States Bureau of Standards 1925, Technological Paper No. 295). This report gives results of quenching experiments with high-carbon steels in which the speed of cooling was determined at the centre of spheres, rounds and plates of various dimensions quenched from various temperatures in different cooling media, such as water, 5 per cent. sodium hydroxide, oils, and air. The cooling velocity at 720° C. is taken as the best measure of hardening produced, and relations are developed between this and the size and shape of the steel quenched.

Delbart, *The Effect of Reheating on Cold-Rolled Steels* (Comptes Rendus, 1925, vol. 180, pp. 934-937). Steels containing 0.127, 0.4, and 0.6 per cent. carbon respectively were subjected to cold-rolling with six passes through the rolls alternating with intermediate reheating at 650° to 700°, followed by two final passes. All the cold-rolled steels showed a coalesced cementite. The steels were subjected to mechanical and corrosion tests in the cold-rolled state, and after reheating for ten minutes at temperatures varying from 400° to 900° followed by air-cooling. The results indicate a drop in the tensile strength towards a minimum at about 650° to 700°. Heating to 850° brings about an increase to normal properties. Two other samples with 0.185 and 0.39 per cent. of carbon, respectively, the first with 0.95 per cent. silicon, and the second with 1.07 per cent. manganese were treated in the same manner and tested in the cold-rolled and heat-treated state. It was found that silicon and manganese do not retard the coalescence of cementite to any great extent. Annealing at 700° results in a typical globular pearlite, while heating to 750° produces a more sorbitic structure.

W. Rosenhain and J. McMinn, *The Plastic Deformation of Iron and the Formation of Neumann Lines* (Proceedings of the Royal Society, Series A, June 2, 1925, vol. 108, pp. 231-239). The investigations were undertaken to determine the effect of wide variations in speed of deformation of plastic metals. Three specimens of iron differing in chemical composition were used, and similar results were obtained from all three. Slow deformation caused slip-bands, and deformation by a blow produced Neumann lines, which the authors proved to correspond with the intersection of lamellæ, and not rods, with the observed surface. The investigators produced Neumann lines and then slip-bands on the same samples, and they consider that the appearance of the slip-bands indicated that the Neumann lines were regions presenting obstacles to slip, but were not twinned layers. It was found that the production of slip-bands inhibited for a time the formation of Neumann lines, and the authors connect this with the peculiar behaviour of recently overstrained iron. Spectrograms showed

that deformation caused no drastic change in the lattice structure, and that the mechanism of deformation, whether performed slowly or by impact, is probably the same.

E. Houdremont and H. Kallen, *Speed of Deformation of Metals and their Resistance to Deformation* (Zeitschrift für Metallkunde, Apr. 6, 1925, vol. 17, pp. 128-129). An approximate method for calculating the strength of resistance to deformation and speed of deformation in the dynamic impact bending test is described. Specimens of mild steel and other metals were subjected to impact bending tests and to static bending tests, and it was found that the resistance to deformation of all metals increased as the speed of deformation increased.

H. Hanemann and F. Lucke, *Recrystallisation and Hot Deformation* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1117-1122). Experiments were made on dead soft steel, steel with 0.5 per cent. carbon, and electrolytic copper. The so-called critical degree of cold-working of iron is found to correspond with the lower limit of the recrystallisation capacity. A formula is derived for establishing the relation between the progress of recrystallisation and the degree of deformation in the hot state.

R. H. Greaves, *The Hardness of Electro-Deposited Metals* (Metallurgist, Sept. 25, 1925, pp. 141-143). The author reviews the known facts concerning the hardness of electro-deposited metals and recapitulates some of the theories that have been put forward at various times to explain the phenomena observed. The author's conclusion is that, in order to account for the structure, hardness and internal stress which are observed, it must be assumed that for some reason—probably associated with the influence of the electric field surrounding the cathode—the atoms of the deposited metal do not immediately take up their final position in the crystal lattice of the deposit. As the deposit grows successive layers cease to be under the influence of the external field, leaving the lattice so strained that ultimately slip occurs leaving part of the strain permanent and part as an elastic distortion of the lattice. The former has an effect resembling the hardening due to cold-work, and the latter causes internal stress. An extensive bibliography is given.

K. Heindlhofer, *Mechanical and Magnetic Hardness* (Iron Age, Sept. 3, 1925, vol. 116, pp. 606-608). The author discusses the results of alternating current magnetic readings taken on a large number of hardened ball-bearing races. The magnetic readings were correlated with the mechanical hardness.

E. J. Janitzky, *Trend of Decrease in Tensility and Brinell Hardness by Tempering* (Transactions of the American Society for Steel Treating, Sept. 1925, vol. 8, pp. 324-328). The author offers a mathematical equation for the interpolation of physical properties, such as tensile strength and Brinell hardness as obtained in tempering hardened steel at various temperatures.

A. Sauveur and D. C. Lee, *The Influence of Strain and of Heat on the*

Hardness of Iron and Steel (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 323-329).

A. Stadeler, *Dependence of Wear upon the Microstructure* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1195-1198). Comparative tests of the wearing qualities of steel as rolled and after suitable heat treatment were made on a wear-testing machine of the type of Mohr and Federhaff. The material chosen was a hard-rolled steel of 80 to 90 kilogrammes per square millimetre tensile strength, with carbon ranging from 0.65 to 0.82 per cent. and phosphorus not over 0.035 per cent. Both the untreated and the quenched and tempered specimens were of about the same Brinell hardness, the hardness ranging from 217 as a minimum to 255 as a maximum, averaging about 240. The wear of the untreated steels after 300,000 revolutions of the machine was between 1.67 and 0.98 gramme, of the quenched and tempered it was between 1.00 and 0.69 gramme after the same number of revolutions. The conclusion is that a steel in a fine-grained condition obtained by treatment resists wear much better than the same steel in the normal state as rolled, the hardness being the same in both cases.

K. Honda and R. Yamada, *Some Experiments on the Abrasion of Metals* (Science Reports of the Tôhoku Imperial University, 1925, vol. 14, pp. 63-83; see also Journal of the Institute of Metals, 1925, No. I., pp. 49-72). The amount of wear under different frictional horse-power and under different coefficients of friction was measured with respect to soft metals and carbon steels.

R. Mouillac, *The Herbert Pendulum for Hardness Tests* (Revue de Métallurgie, Mémoires, Apr. 1925, vol. 22, pp. 223-237). Four kinds of tests, each indicative of a different mechanical property of metal, can be carried out by the Herbert pendulum. They are:

1. Hardness tests, showing the resistance of the material to penetration.

2. Amplitude tests, showing the resistance offered by the material to the tool used in machining it.

3. Work-hardening tests showing the degree to which a metal work-hardens and the extent of the resulting transformation.

4. Shock absorption tests, which show the rate at which the metal absorbs energy under the influence of successive deformations.

Experiments in each kind of test and the results obtained are described in detail. The largest machine had a pendulum 25 kilogrammes in weight, and a steel ball 3 millimetres in diameter.

L. Guillet and J. Galibourg, *Some Results of Tests with the Herbert Pendulum* (Revue de Métallurgie, Mémoires, Apr. 1925, vol. 22, pp. 238-244). An investigation was undertaken to ascertain what indications the pendulum testing machine may be expected to yield in regard to properties not shown by other kinds of test, or not so accurately established by such tests. Case-hardened parts sometimes show local soft spots owing to local heating, and hitherto only file tests have revealed these. The Herbert pendulum has successfully revealed

such differences, where the Brinell, scleroscope, and sclerometer methods have failed.

P. Nicolau, *Remarks on the Use of the Herbert Pendulum* (Revue de Métallurgie, Mémoires, Apr. 1925, vol. 22, pp. 245-250). Some modifications intended to improve the design and construction of the machine are put forward as suggestions. Instances of variation in the results due to the personal equation of the operator are given. "Time tests" by the machine range the materials in the same order as the Brinell test, but reveal total deformation under static stress, whereas the Brinell test does not reveal elastic deformation.

Hardness Testing Device (Machinery, June 4, 1925, vol. 26, p. 316). A description is given of a simple device for testing rapidly small hardened steel rollers made in large numbers. It was actually set up near the quenching tank in the hardening department and as each lot of rollers was removed from the tank a few samples were tested. If the tests showed that the rollers were too soft or too brittle the whole lot was returned for another heat treatment.

New Rockwell Hardness Tester (Forging, Stamping, Heat Treating, Aug. 1925, vol. 11, p. 284). A brief description and a photograph of the latest model of the Rockwell hardness tester is given. It has been designed for examining very large pieces.

E. S. Ault, *A Comparison of Modified Ball-Indentation Hardness Numbers* (Mechanical Engineering, Sept. 1925, vol. 47, pp. 732-734). The author presents a summary of the search for a single number to express indentation hardness independently of the load and the diameter of the ball, and a comparison of the various methods when applied to accepted data. A useful bibliography is appended.

Pendulum Impact Testing Machine (Machinery, Sept. 17, 1925, vol. 26, pp. 793-794). A new form of impact testing machine made by Messrs. A. J. Amsler & Co., Schaffhausen, Switzerland, is described and illustrated. The outstanding feature of this machine is that, in addition to performing the ordinary transverse shock tests, on notched and unnotched test-bars of various cross-section and length, it is possible, by a simple adjustment, to make shock tests on bars of determined form, and also on wire rope specimens.

Endurance Impact Testing Machine (Engineering, May 15, 1925, vol. 119, pp. 604, 608). *Impact Testing Machine* (Machinery, May 28, 1925, vol. 26, p. 283). Two short notes, the former illustrated, describe the new testing machine recently produced by Messrs. A. J. Amsler & Co., Schaffhausen, Switzerland. It is designed to carry out tension impact, compression impact, and transverse bending impact tests.

Holding Constant Load in Testing Machine (American Machinist (European Edition), July 25, 1925, vol. 62, p. 179E). Describes a device made by Messrs. A. J. Amsler and Co., Switzerland, for automatically holding the load on a test-piece for any desired length of time.

Fatigue Tests of Metals (Génie Civil, July 18, Aug. 15, 1925, vol. 87, pp. 64-66, 152). An illustrated description is given of the Amsler machine as adapted for the duration testing of springs, rotary bend tests, and repetition drop and wear tests.

H. Meyer and W. Wesseling, *Change in the Tensile Properties of Pearlite Steels Due to Heat Treatment* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1169-1173). The relation between the structure and properties of highly pearlitic steels is considered, four steels being used for the investigation, containing respectively 0.740, 0.935, 1.15, and 1.06 per cent. carbon. These steels were submitted to various heat treatments and were tested for their tensile properties after each different treatment, the results being presented in a number of tables. It might reasonably be expected that changes in the tensile properties of highly pearlitic steels would be accompanied by changes in the microstructure, but the interpretation of the micrographs of such steels is not easy. Grain-size and grain formation in pearlitic steels depend upon the heat treatment, and observation should be directed to the form of the pearlite growth and the size of the two structured elements, granular pearlite, and banded pearlite. In the granular pearlite the grain size of the ferrite ground mass and the cementite grain therein should be specially noted, and in the banded pearlite the actual and apparent grain-size. The actual pearlite grain-size bears no simple relation to the grain-size of the solid solution and the ordinary etching methods yield no satisfactory indications. The temperature range within which the properties of steels are influenced by the formation of granular pearlite is wider than is usually supposed, and the form of pearlite development is of greater importance than the grain-size in their respective influence on the tensile properties. The influence of the pearlite grain-size must be tested in conjunction with the use of a suitable etching reagent, and the authors are continuing their investigations in this direction. The effect of increasing grain-size due to higher annealing temperatures is reflected in the tensile test results, especially in the low degree of toughness of specimens slowly cooled from the higher annealing temperatures.

R. S. Johnston, *Strain Detection in Mild Steel by Wash Coatings* (Communication to the Iron and Steel Institute, Sept. 1925: this Journal, pp. 341-342).

P. Bardenheuer, *Internal Stresses in Rolled Bars, with Special Reference to Rails* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1098-1101). A general discussion of the causes of stresses in rolled bars. In rails, owing to the unfavourable distribution of the mass of the material, such stresses may be unduly high; these are brought about by the uneven shrinking of the component parts of the rail and the internal stresses due to irregular cooling are in general greater than those due to the mechanical action of rolling. The stresses are greatest in the case of rails rolled from material which is not uniformly hot throughout at the beginning of the rolling, particularly if the ingot is not completely

solidified in the centre. The irregular distribution of sulphur in the rail is characteristic of rails rolled from ingots still liquid internally, as is shown at once by the application of the Baumann test for sulphur to the polished surface of a steel rail.

J. Seigle and F. Cretin, *The Elastic Limit and Resistance of Annealed Mild Steels, in the Case of Combined Tensional and Torsional Stresses* (Revue de Métallurgie, Mémoires, June 1925, vol. 22, pp. 374–382). A mathematical consideration, with formulæ, of the factors involved, and an attempt to reconcile the discrepancies between the competing theories on the rupture of the elastic equilibrium, put forward by Rankine, Saint Venant, and Coulomb, with the theory of maximum shear, or frictionless slip. The question of fatigue enters largely into the problem of the behaviour of steel under combined tension and torsion stress and is considered in detail.

J. Seigle, *Tests of Mild Steel under Combined Stress* (Comptes Rendus, 1925, vol. 181, pp. 98–99). The results of torsion tests on mild steel bars while in a state of constant tension or compression are discussed. The bars were tested both in the annealed and in the cold-worked condition. The maximum elastic moment towards torsion is diminished as either the tensile or compressive stress increases. The moment of rupture by torsion decreases greatly as the tensile force is increased, but increases with the compression. Rupture always occurs at right angles to the bar.

G. Welter, *Measurement of Tensile Strength and Elasticity by Dynamic Methods on the Pendulum Testing Machine* (Zeitschrift für Metallkunde, Apr. 1925, vol. 17, pp. 109–111). In continuation of his previous work the author has devised a method of recording separately on the pendulum impact testing machine, the work expended in testing a material up to the limit of elasticity and the further amount of work expended in producing rupture after passing the elastic limit. The experiments lead to the conclusion that the static elastic limit is equal to the dynamic elastic limit. The method affords a means for studying the behaviour of iron and other metals when stressed above the elastic limit.

T. D. Lynch, N. L. Mochel, and P. J. McVetty, *Tensile Properties of Metals at High Temperature, Showing Effect of Stress and Time* (Paper read before the American Society for Testing Materials, June 1925). The importance of long time (sustained loading) tests to engineers is discussed. It is shown that the proportional limit of the short time tensile test has a definite physical meaning at high temperatures for medium carbon steel and that continuous creep at or below this stress is not to be expected. On the other hand, this is not true for the non-ferrous metals tested.

A. L. Kimball, jun., *Photo-Elasticity and its Relation to Gear Wheels* (American Machinist (European Edition), Aug. 8, 15, 1925, vol. 63, pp. 7–10, 51–54). The photo-elastic method is a means by which the stress in loaded structures can be directly determined by polarised-light measurements on transparent models. It had long

been known that transparent materials, when stressed, become doubly refracting, and in that state have a peculiar effect on rays of polarised light passing through them.

The author gives a brief explanation of the production of the circularly polarised light employed, and the method of employing it. On a screen, or photographic plate, colour bands appear when the model is strained, but these bands can be made to give a direct measure by calibration. It has been found possible to examine the stress in gear-wheel teeth cut in celluloid not only under static load, but also while forming part of a train of wheels, an arrangement of electric sparks giving a stationary image of the moving object. The method is at present only applicable to stresses in a plane at right angles to the path of the polarised light, and so torsional stresses cannot yet be examined by its means. Of course the actual stresses set up in a celluloid model are not so great as would occur in the metal originally, but the distributions are similar, provided the elastic limit is not exceeded; the stresses obtained do not include any initial stresses in the metal member. The body is assumed to be isotropic; the crystalline structure must be small compared with the boundary irregularities.

P. Heymans, *A Study of the Causes of Fracture of Metal Structures by Means of Polarised Light* (Revue Universelle des Mines, May 15, 1925, vol. 6, pp. 207-211). A number of pinions of electric traction motors which failed by fracture came under the author's notice. Examination showed that the metal was sound and that the pinions had not been called upon to transmit a heavier load than that for which they were designed. Finally a comparison was made of the shape of the fractures and the strain lines which can be made to appear when a celluloid model of the article is stressed and examined by polarised light. The solution was then not far to seek. The pinions had their bore slightly tapered and were fastened by raising them to the temperature of boiling water and sliding them on to the correspondingly tapered shaft. On cooling the thermal contraction was enough to hold them firmly in place. An inexperienced workman, who had apparently feared that the hold would be insecure, had heated the pinions in a furnace before sliding on to the shaft and then to make sure had driven them home with a heavy forge hammer. The celluloid models showed very clearly that the excessive transverse radial strain was the cause of all the trouble, and that the form of fracture depended very much on what radial strain was imposed.

C. W. Yearsley, *A Physico-Chemical Interpretation of the Effects of Stress upon Metals* (Journal of the Birmingham Metallurgical Society, vol. 8, No. 4, pp. 129-143).

R. H. Greaves and J. A. Jones, *The Effect of Temperature on the Behaviour of Iron and Steel in the Notched-Bar Impact Test* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 123-162).

S. N. Petrenko, *Comparative Slow Bend and Impact Notched-Bar*

Tests on Some Metals (United States Bureau of Standards, 1925, Technologic Paper No. 289). Comparative impact and slow-bend tests on notched bars were made on some non-ferrous alloys and steels in order to determine whether the slow-bend test may be used as a substitute for, or an addition to, the impact test. The tests were made on an Izod pendulum type impact machine, and a Humfrey slow-bend machine. The effect of the shape of the notch on the impact and on the slow-bend values was also studied. The slow-bend tests gave values lower than the impact for non-ferrous materials and higher than the impact for steels. Wherever the variation of the notched bar values is present in specimens of the same material, whether this variation is due to the shape of notch or to its position in respect of direction of rolling, the slow-bend test gives results comparable with those of the impact test, but it is less responsive to these variations than the impact test. By means of a bending moment diagram the slow-bend test gives some values which are related to the tensile yield point and to the tensile strength of the materials. It is, however, less convenient than the impact for ordinary routine practice.

R. Mailänder, *Influence of the Width of Test-Piece on the Notch Toughness of Mild Steel* (Stahl und Eisen, Sept. 17, 1925, vol. 45, p. 1607). A short note is given in continuation of the author's previous work (Kruppsche Monatshefte, 1924, vol. 5, pp. 16-21) in explanation of the fact that the line of maximum values in which the single curves unite, as shown in his tests, does not necessarily pass through the zero point of the co-ordinate system, as other workers have assumed. The position of the line is dependent upon the depth of the notch.

F. Körber, *Relation between Notch Toughness and Slip Plane Formation* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1146-1149). Two series of iron-silicon specimens, containing respectively 3.03 and 5.12 per cent. silicon were tested for notch toughness at different temperatures and subjected to microscopic examination. The number of slip planes was found to increase as the toughness increased, leading to the conclusion that a close relationship exists between the capacity for the formation of slip planes and the mechanical behaviour of the material.

F. Laszlo, *The Utilisation of the Impact Bending Test on Notched Bars* (Stahl und Eisen, Aug. 20, Sept. 3, 1925, vol. 45, pp. 1413-1422, 1521-1522). A critical discussion of Fillunger's work by which he endeavoured to establish, by mathematical calculation, a relation between the dimensions of the test-piece and the work of rupture; also of Moser's work in which he sought to establish the influence of increasing the width of the test-bar, without changing the other dimensions and using the same speed of impact. The author argues that the chief value of the notch-bar impact test consists in furnishing evidence by mechanical means concerning the metallographic state of the metal, and that the test is of less use in determining the tensile properties. To determine separately the equivalent notch toughness

and speed of work considerably increases the usefulness of the test, but for determining the tensile properties the development of impact tensile test will prove more useful.

F. Körber and A. Pomp, *Influence of Heat Treatment on the Mechanical Properties of Carbon and Alloy Steels, Particularly as Regards Notch Toughness at Low and High Temperatures* (Mitteilungen a.d. Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 7, Pt. 4, pp. 43-57). The materials chosen for the tests were five carbon steels with carbon ranging from 0.05 to 1.00, and one nickel-chrome steel with nickel 2.75, chromium 0.78 per cent. Specimens were tested in the rolled condition as delivered, overheated and quenched from above the A3 point in water, and subsequently tempered for half an hour in a salt-bath at 650° C. The bars were then notched and tested on the Charpy impact testing pendulum machine at temperatures from -200° and -70° up to 500°. For the carbon steels as rolled and overheated notch toughness values were low at temperatures below zero, the higher the carbon the lower being the notch toughness value. Above zero the values rose rapidly, reaching a maximum at different temperatures, depending upon the composition of the steel, and falling rapidly after about 300° C. The nickel-chrome steel, especially in the quenched and tempered state, showed high notch toughness values at temperatures as low as -100°, rising to about 16.8 kgm. per square centimetre at -50°, or very little lower than the maximum of 17 kgm. per square centimetre reached at 100° C.

Temperature and the Izod Impact Test (Machinery, May 28, 1925, vol. 26, p. 280). Trouble was experienced with a series of test-pieces which consistently gave low results, although they had been very carefully heat-treated. It was found that the test-pieces had been laid on a cold iron bench in a very cold position before breaking, and this lowering of temperature was sufficient to reduce the impact test results below the required specification. That the pieces were not really faulty was proved by re-testing them after they had been warmed up again by dipping in warm water.

P. L. Irwin, *Fatigue of Metals by Direct Stress* (Paper read before the American Society for Testing Materials, June 1925). An improved fatigue testing machine is described, in which the endurance limits of metals may be determined under direct stress (cycles of tension-compression). Comparisons are given for various steels and forged manganese-bronze to show that the endurance limit obtained by direct stress is the same as that obtained by the more commonly used flexural stress tests.

T. M. Jasper, *Typical Static and Fatigue Tests on Steel at Elevated Temperatures* (Paper read before the American Society for Testing Materials, June 1925). The author discusses the endurance limits at various temperatures of some wrought ferrous metals and their relation to typical tensile tests. Attention is drawn to the fact that, at temperatures above from 400° to 600° F. the tensile strengths are materially

lower when tests are made with very slow increase in load above the proportional limit than when carried out at ordinary laboratory speeds of testing. It is suggested that similar effects are to be expected in fatigue strengths. An explanation is attempted for the increase in tensile strength at blue heat of normalised medium carbon steel.

P. Billet and H. Wantz, *Tests on the Fatigue of Metal in the Tires of Railway Wheels* (Revue de Métallurgie, Mémoires, Mar., Apr. 1925, vol. 22, pp. 154-169, 207-217). The considerations which govern the manufacture and construction of locomotive wheels are to a considerable extent empirical, and hence it is usual to allow a very large factor of safety. A highly detailed account of the conditions to be satisfied is given. The proper adhesion of a tire to its wheel depends upon a number of considerations some of which it is not easy, in practice, to reconcile. The dilatational properties of a tire have, of course, to be brought into play, but in proportion as they are excessive, owing to the tire having been overheated, they secure firmer adhesion at the expense of setting up severe stresses, thus inducing premature fatigue, with its resulting changes, in the metal of the tire itself. On the other hand, if it be sought to eliminate these stresses by heating the tire only to the extent necessary to secure a degree of unstressed adhesion, it will tend to work loose or may even fracture owing to impact shocks, and in other ways prove more dangerous still. A further very important factor is the condition of the metal constituting the wheel centre or hub. If this be fairly elastic, it will tend to take up and slightly compensate for some of the stresses set up by a very tightly fitting tire. The arguments deducible from these considerations support the view that safety is best attained by using solid wheels, made in a single piece and with specially hardened treads. In practice, however, the solution is not really as simple as this. The problem involves (1) a mathematical research on the elastic stresses in tires, and (2) the experimental determination of the elasticity of hubs of various kinds and composed of metal of varying properties. The conclusions arrived at are that the solid wheel is, after all, the only type from which the best and safest results can be obtained, the conflicting requirements in the case of wheels having a tire shrunk on to them being such as to occasion inevitable dangers. Many illustrations are given showing the microstructure and the macrostructure of tires which have been overstrained and have, in consequence, failed in practice.

H. Kändler and E. H. Schulz, *New Method of Reducing the Risk of Failure due to Fatigue* (Stahl und Eisen, Sept. 17, 1925, vol. 45, pp. 1589-1596). When a steel bar in which a V-shaped notch has been turned is subjected to acid attack, it is noticeable that the rate of dissolution of the steel material is more rapid within the notch and at the edges of it than on the plain surface of the bar. The notch soon becomes rounded at the bottom, and, in fact, the more acute the angle of the V, the more rapid is the action of the acid in widening and

rounding the notch. On submitting specimens in the form of round bars provided with a V-shaped notch to endurance tests, first, as machined, and, secondly, after attack for varying periods in hydrochloric or nitric acid, the specimens treated with acid show a considerably increased resistance to the endurance tests. Further, it is found that plain bars, showing very light tool markings after turning, will stand a much higher number of stress reversals or blows after immersion for, say, ten hours in concentrated hydrochloric acid. Diagrams and tables are given showing the results of numerous tests, and comparative curves show that, in the case of plain bars $\frac{1}{8}$ inch diameter, the resistance of the plain turned bar, unattacked, was 11,600 blows in the Krupp endurance-testing machine and 16,500 after ten hours' attack with concentrated hydrochloric acid. A polished bar of the same size had a resistance number of 12,000 when unattacked and 15,100 after attack. It is suggested that parts of structures particularly exposed to repeated shock should be acid-treated before putting into service.

C. F. Jenkin, *High-Frequency Fatigue Tests* (Proceedings of the Royal Society, Series A, Sept. 1, 1925, vol. 109, pp. 119-143). The experiments were carried out on copper, Armco iron, and mild steel. Frequencies up to 5000 cycles per second were employed, and the necessary apparatus is fully described and the results are tabulated. In an appendix are included the mathematics covering the vibration of a beam supported at the nodes, with free ends; this information is necessary for evaluating the experiments in order that a measurement of amplitude of vibration may be used as a measure of the strain produced.

D. J. McAdam, jun., *Endurance Properties of Metals* (Mechanical Engineering, July 1925, vol. 47, pp. 566-572). The author first discusses the causes of fatigue failure, and then gives the results of a large series of experiments made on various metals and alloys, including steels and alloy steels, to determine the relationship between the stresses employed and the resistance of the materials to fatigue. Experimental results are also given showing the effect of cold-working and heat treatment. Copious references to recent literature are added.

H. F. Moore, *Studying the Fatigue of Metals* (American Machinist (European Edition), May 30, 1925, vol. 62, pp. 563-565). A brief description is given of the laboratory at the University of Illinois devoted to this study, and also of the work carried out there by the author and others with special reference to researches on fatigue of ferrous metals.

R. R. Moore, *Fatigue of Welds* (Mechanical Engineering, Oct. 1925, vol. 47, pp. 794-795). A brief description is given of a new machine designed by the Engineering Division of the Air Service, U.S.A., to apply repeated flexural stresses to welded joints in tubular members such as form part of the fuselage of airplanes. Experiments are not yet completed, but so far they seem to indicate that welded joints

are much weaker under repeated *flexural* stresses than was thought. Tests indicate that the endurance limit of a welded tube is only about 50 per cent. of that of a similar plain tube. An interesting point brought out by the tests is the location of the fracture. In the static tension test a torch-welded specimen breaks about $\frac{1}{2}$ inch to 1 inch from the weld, probably on account of the softening of the tube by the heat of the flame, and the extra strength of the weld owing to its larger cross-sectional area due to added welding metal. In the repeated flexural test the fracture always occurs through the weld. In the case of arc-welded tubes fracture occurs in both tests through the weld itself, as the heating is localised.

H. C. Dews, *The Growth of Modern Theories of Fatigue Failure* (Metal Industry, June 5, 1925, vol. 26, pp. 551-553). Following a survey of the older ideas on the subject, such as "crystallisation," the modern theories of Rosenhain and Merrils, which are based on opposing hypotheses, are fully discussed.

American Specification for Commercial Bar Steel (Iron and Coal Trades Review, May 15, 1925, vol. 110, p. 798). Particulars are given of the recently issued specifications of the Association of American Steel Manufacturers for bar steels of commercial quality and special forging quality. Commercial quality bar steel is described as "hot-rolled carbon steel bars produced in accordance with good mill practice for general commercial practices." The specification for forging quality steel is to cover bars bought for forging purposes and subject to heat treatment. A revision has been made of the Association's standard methods of sampling steel products.

United States Government Master Specification for Wire Rope (United States Bureau of Standards, 1925, Circular 208).

United States Government Master Specification for Medium and Light Rust-Preventive Compounds (United States Bureau of Standards, 1925, Circular 214).

Commercial Steels (Foundry Trade Journal, July 23, Aug. 6, 13, 1925, vol. 32, pp. 86-87, 121-122, 138). Brief particulars are given of the properties of some commercial special steels.

J. C. Brown, *Breaking of Rails* (Report to International Railway Congress, June 22, 1925: Iron and Coal Trades Review, July 3, 1925, vol. 111, p. 3). From replies received in response to a questionnaire on breakages of rails the maximum axle load generally adopted on British railways would appear to be about 20 tons, while the maximum speeds are stated to be from 60 up to 80 miles per hour. The section of rail adopted for fast and heavy traffic on British lines ranges in weight usually from 90 to 100 lbs. per lineal yard, and for other lines from 75 to 85 lbs. per lineal yard. While most of the breakages of rails occur near the joints, there does not appear to be any evidence that the fish-bolt holes, if properly made, are in themselves an active cause in initiating breakage.

Replies to the questions relating to breakages due to defects in the

metal show that the general view is that segregation and piping can only be guarded against by sufficient cropping of the ingot and rail. Several replies agree that the local defects may be due to lack of protection of the rails during cooling, and indicate the importance of suitable means being provided for covering the cooling banks. So far no breakage appears to have been attributable to transverse fissures in the metal, which have caused so much trouble in the United States, due no doubt to the fact that maximum axle weights in this country are so much less than those on the American railways. Many of the companies are using or experimenting with special steels with the object of decreasing the amount of wear. On the Metropolitan Railway sorbitic, high silicon, and manganese steel rails are in use, and out of a total of twelve breakages in the last seventeen years, about half occurred in the high silicon and manganese rails. The incidence of excessive wear on certain stretches of this railway, however, on which these special steels are used does not permit of any conclusion being drawn in any way detrimental to the use of special steels. One or two companies indicate certain practices in the manufacture of rails which they consider should not be allowed. In one instance objection is taken to the cutting of rails when cooled with high-speed saws, on the ground that such treatment renders the end of the rail very hard. It is also considered that the finishing temperature of the rails should not be too high, in order to avoid brittleness, and the maximum of 1000°C . is suggested. The compulsory casting of ingots in inverted moulds is also advocated.

R. L. Rolf, *Inspecting and Testing Automobile Axles* (Forging, Stamping, Heat Treating, July 1925, vol. 11, pp. 226–231 and 240). An illustrated description of the many and rigorous tests applied to these important components of motor-cars.

Detection of Cracks in Axles and Pinions by the Electro-Magnetic Method (Tramway and Railway World, Aug. 20, 1925, vol. 58, pp. 102–103). The process adopted by the London County Council tramways shops to discover hair cracks, in axles and pinions, invisible under a magnifying glass, is described. Briefly, the axle is magnetised and while in this condition a mixture of paraffin oil and iron powder, with calcium chloride added to prevent the presence of moisture, is flowed over it. The solution runs off if there are no cracks, but the powder clings to a hair crack, however small, and shows a comparatively thick line, thus indicating the position of the crack.

The Detection of Flaws in Metal Masses (Engineering, May 29, 1925, vol. 119, p. 679). Burrows and Fahy of the Bureau of Standards, Washington, and others have devised methods of magnetic analysis, which indicate not only the character of the steel, but also any lack of homogeneity due to any cause whatever, and these methods are in everyday use for the detection of flaws in sections ranging in size up to steel rails. For large sections such as the rotors for turbo-generators, the methods become too insensitive, and to meet this difficulty a method

of flaw detection has been invented, which is based on a drop of electric potential. A fairly large direct current is passed through the section, and the potential drop along a certain distance is measured by means of two rigidly fixed insulated steel points connected to a sensitive galvanometer. The presence of a flaw is indicated by the rise in the potential drop as the probing points are moved along the mass of the section. The method is simple, but great care is needed and precautions have to be taken to avoid being misled by the effect on the galvanometer caused by changes of contour of the section.

C. Benedicks, *The Hardening and Hardness of Carbon Steel, High-Speed Steel, and other Alloys* (Stockholm, 1925: P. A. Norstedt and Söner, 76 pp.).

A. R. Page, *High-Speed Steel* (Journal of the Birmingham Metallurgical Society, vol. 8, No. 10, pp. 447-468). The author discusses the constitution, properties, heat treatment, and testing of high-speed steel.

L. Guillet, *High-Speed Tool Steels Containing Cobalt* (Revue de Métallurgie, Mémoires, Feb. 1925, vol. 22, pp. 88-91). Very contradictory views are held concerning the value and future prospects of tool steel containing cobalt. These steels have the usual composition of high-speed tool steel, with the addition of cobalt, and the types experimented with contained chromium, vanadium, tungsten, molybdenum, and from 1 to 3 per cent. of cobalt, and 5 per cent. of cobalt. The heat treatment is described. It was found that a cobalt steel develops the same hardness on quenching at 1100° C. as a steel not containing cobalt, quenched from a higher temperature. Thus, even if cobalt does not greatly improve the quality of a tool steel it renders its heat treatment easier by lowering the temperature of hardening.

Cobalt Steels for High-Speed Cutting Tools (Metallurgist, Sept. 25, 1925, pp. 139-140). An abstract in English of the foregoing paper by L. Guillet.

K. Sasagawa, *Investigations on High-Speed Tool Steels with and without Cobalt* (Revue de Métallurgie, Mémoires, Feb. 1925, vol. 22, pp. 92-106). The influence of cobalt on the dilatometric transformations of steel, and on its hardness, density, and structure was investigated. Comparative tests were undertaken with two steels containing 14 and 19 per cent. of tungsten, but with neither molybdenum nor cobalt, and a 10 per cent. tungsten steel with 0.8 per cent. of molybdenum and 5 per cent. of cobalt. The Chevenard differential dilatometric method was employed, the rates of heating and cooling being varied during the experiments. The heating transformation of an annealed cobalt steel occurs at a lower temperature and is completed much more rapidly in a steel containing cobalt than one not containing that element. In regard to cooling transformations a steel containing cobalt is intermediary between a tungsten steel containing 14 per cent. of tungsten and one containing 19 per cent. (actually 18.98 per cent.). The structure due to different heat treatments is illustrated. The cobalt is invariably found in the white constituent, and it is evident that a transformation

in which this element is conclusively concerned occurs at 770°C . The conclusion is reached that the hardening of cobalt steels can be carried out at a lower temperature than that necessary in the case of an ordinary high-speed steel containing 19 per cent. of tungsten. A bibliography of the literature of cobalt steels is given.

W. H. Losee, *Manufacture and Uses of Stellite* (Journal of Society of Chemical Industry, Sept. 4, 1925, vol. 44, pp. 451-452T). A description is given of the metallurgical operations involved in the manufacture of stellite and the casting of the alloy into graphite moulds and the subsequent grinding of the bars to form cutting tools.

Stellite and Similar Alloys (Stahl und Eisen, June 11, 1925, vol. 45, pp. 945-947). A general summary is given of the characteristics and properties of chromium-cobalt-tungsten alloys. The influence of heat treatment on the K-S magnet steel, invented by Honda and Saito, is shown, and similar information is given concerning another alloy of nearly the same composition prepared by E. H. Schulz and W. Jenge. Results of comparative cutting tests are shown, the materials tested being stellite, high-speed steel, carbon tool steel, and Akrit. In these tests Akrit appears to give results much superior to those obtained with high-speed steel. Three other similar alloys have now appeared on the market, namely, Celsit by Böhler Bros., Caedit by the Glocken Stahlwerke, and Percit by Krupp.

E. Maurer and G. Schilling, *The Technology of High-Speed Steels* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1152-1169). The authors have tested the observations of many previous investigators, including Arnold, Osmond, Le Chatelier, McCance, Benedicks, Grossmann and Bain, Archer and Jeffries, Honda and Murakami, and largely by means of electric resistance measurements, cutting tests, and tensile tests they confirm in general the results obtained by those workers.

G. Z. Nesselstrauß, *High-Speed Steel, Its Physico-Chemical Nature and Technical Properties* (Annales Inst. Anal. Phys.-Chimie, Leningrad, 1924, vol. 2, p. 484). A study of the microstructure and thermal transformations of a chrome-tungsten steel containing carbon 0.4, chromium 4, and tungsten 19.5 per cent.

R. Hohage and A. Grützner, *Cutting Tests with High-Speed Steels* (Kruppsche Monatshefte, June 1925, vol. 6, pp. 105-112). The object of the tests was more especially to determine the influence of the individual elements in the alloys. The results, plotted in curves, show that with tungsten between 14.3 and 23.8 per cent., 1 per cent. of tungsten is the equivalent of 0.12 per cent. vanadium, and of 0.6 per cent. molybdenum. In general, in high-speed steels with normal carbon and chromium contents, tungsten, vanadium, and molybdenum have a balancing relationship, but only up to a certain maximum amount. The maximum efficiency is attained in a steel containing tungsten 13.8, vanadium 1.6, molybdenum 4 per cent.; or, alternatively, tungsten 23.0, vanadium 0.8 per cent., with no molybdenum. The efficiency tests with these two steels gave equal results.

R. Hohage and A. Grützner, *Cutting Tests with High-Speed Steels* (Stahl und Eisen, July 9, 1925, pp. 1126–1130). A series of twenty-five high-speed steels, containing varying proportions of chromium, tungsten, and vanadium, were tested. The results are as recorded in the foregoing article.

T. E. Stanton, *An Experimental Study of the Forces Exerted on the Surface of a Cutting Tool* (Proceedings of the Institution of Mechanical Engineers, 1925, No. 1, pp. 175–194). The author presents the results of a series of observations of the effect of frictional and abrasive forces upon the cutting action of tools. Certain other important characteristics revealed during the investigation are also discussed.

E. G. Coker, *Report on the Action of Cutting Tools* (Proceedings of the Institution of Mechanical Engineers, 1925, No. 1, pp. 357–382). The author presents the result of an investigation of the cutting action of planing and milling tools. The stresses produced by the tools were measured by observations of the colour bands produced by polarised light.

Dempster Smith and A. Leigh, *Experiments with Lathe Tools on Fine Cuts, and some Physical Properties of the Tool Steels Used and Metal Operated on* (Proceedings of the Institution of Mechanical Engineers, 1925, No. 1, pp. 383–408).

J. A. Jones, *The Influence of Tungsten on Medium Carbon Steels containing Nickel and Chromium* (Woolwich, Research Department, 1925, Report No. 65). The thermal critical ranges, microstructure, and mechanical properties of a number of carbon, nickel, and nickel-chromium steels containing tungsten were examined. In steels of otherwise identical composition, increasing tungsten content very slightly raises the temperature of Acl (maximum). The rise amounts to about 8° C. for the addition of 1 per cent. of tungsten in the carbon steels, and is less in the other series. At the rate of cooling employed, Ar1 (maximum) of the carbon-tungsten steels was hardly affected by increase of tungsten content, while such increase had a pronounced effect in lowering the Ar1 point of nickel and nickel-chromium steels.

Correlation of hardness, microstructure, and heat treatment of small pieces shows that tungsten behaves like other alloy elements in increasing the efficiency of hardening at the slower rates of cooling such as are involved in the heat treatment of large masses. Its effect in this direction is most pronounced when added to nickel steels containing about 6 per cent. of nickel. Addition of tungsten also reduces the fall of hardness produced by tempering—an effect which is more apparent in the nickel-tungsten steels than in those which also contain chromium, since chromium itself has a similar effect.

The carbon-tungsten steels containing up to 1·7 per cent. of tungsten, and the 3·5 per cent. nickel-tungsten steels containing less than 1·5 per cent. of tungsten, with a carbon content of 0·3 per cent., will not give sufficiently good mechanical properties to be considered as high tensile constructional steels.

The steel, amongst those examined which contained tungsten, giving most promise of useful application was the 6 per cent. nickel steel, with 0.6 to 1.0 per cent. tungsten.

In general it may be stated that while tungsten, in common with other alloying elements, exerts a beneficial effect on the properties of steels of the type used for constructional and similar engineering purposes, there is nothing so distinctive in its influence as to warrant any special recommendation in favour of its adoption.

C. H. S. Tupholme, *Some Alloy Steels for Automobile Construction* (Metallurgist, July 31, 1925, pp. 98-101). The author discusses a fairly wide range of alloy steels containing chromium, nickel, chrome-nickel, chrome-vanadium, and chrome-molybdenum. The various classes are arranged with the alloying element gradually increasing, so that the change of physical properties and behaviour on heat treatment, caused by small changes of composition, may be easily noted. Tables of each type of alloy are included showing the chemical composition of each individual steel and indicating those parts of a motor-car for which it is specially suited.

Mahoux, *Note on Valves* (Revue de Métallurgie, Mémoires, Jan. 1925, vol. 22, pp. 39-51). An investigation of the behaviour of valves of the mushroom type, made from different kinds of steel, under the severe service conditions required in modern high-speed aero and other engines. The steels must be fairly rustless and must withstand the action of hydrocarbons. Some nickel steels are defective in this respect. Careful design is, moreover, necessary, and the adjustment of the mass of metal in the mushroom head and in the stem, respectively, requires careful consideration. A number of complete analyses, with comments on the behaviour in practice of the various steels to which they relate, are given. The steels so enumerated include all the varieties of chromium, nickel, tungsten, silicon, and vanadium steels ordinarily employed for the purpose.

F. W. Duesing, *Principles of Heat Treatment of Some Special Steels in General Use* (Mitteilungen a.d. Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 6, No. 8, pp. 71-135). The steels used for the heat-treating experiments were eight in number—namely, one manganese steel (manganese 0.98 per cent., with small percentages of nickel and chromium), one manganese-silicon steel (manganese 0.94, silicon 0.76 per cent.), two nickel steels (nickel 2.15 and 2.38 per cent.), three chrome-nickel steels (chromium 0.31, nickel 2.60; chromium 0.79, nickel 3.83; and chromium 0.54, nickel 3.84 per cent. respectively), and one chromium steel (chromium 1.31 per cent.). These were all structural steels, and their critical points on heating and cooling were examined. Thermal analysis was followed by determination of the hardness and a study of the microstructure of the test-pieces, which were quenched from varying temperatures within the range of transformation. It was found that the thermal analysis did not yield satisfactory information concerning the Ac3 point of steel alloys, upon which

so much depends in the heat treatment of a steel. This point could only be accurately determined with the aid of a quenching treatment, as confirmed by examination of tensile bars hardened at successive stages. The influence of annealing was studied by annealing test-pieces at temperatures from 600° to 1000°, and the changes in the tensile properties due to the treatments were determined by tensile and impact tests and examination of the microstructure. The influence of quenching in air, oil, and water, with subsequent tempering, was studied, and a number of specimens were subjected to the impact tensile test. It was clearly brought out that the work expended in the impact tensile test is considerably more than in the static tensile test. The actual results are presented in numerous tables.

Manganese Steel (Iron and Steel of Canada, June 1925, vol. 8, p. 117). A short account of the mechanical and physical properties of this steel is given.

E. Piwowarsky, *Phosphide in Manganese Steel* (Stahl und Eisen, July 2, 1925, vol. 45, pp. 1075-1076). For certain objects such as tube mandrils, rolling-mill pinions, railway switches and frogs, car wheels and steel helmets, manganese steel containing 10 to 14 per cent. manganese is used. Owing to a certain percentage of phosphorus (up to 0.3 per cent. sometimes) in ferro-manganese, such steels have been found to contain up to 0.13 phosphorus. In a specimen examined by the author containing 0.13 phosphorus, micrographs indicated the presence of free phosphide along with free carbide as structural components. To distinguish these compounds the specimen was etched according to Matweieff's method with picrate of soda, and the compounds were successfully revealed. After heating *in vacuo* for fifteen hours at 1050° C., and quenching in cold water, both free carbide and free phosphide had disappeared, having gone into solution, and there remained only homogeneous austenite, thus proving that the phosphide-bearing eutectic, as a heterogeneous constituent, had separated out in consequence of insufficient diffusion of the primary mixed crystals.

Nickel Steel (Machinery, May 28, 1925, vol. 26, pp. 277-279). After a brief history of the introduction of nickel steel, an account is given of the metallurgy and properties of the alloys.

P. Bardenheuer, *Flakes in Nickel-Chrome Steel* (Mitteilungen a.d. Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 7, Pt. 1, pp. 1-15). After a brief review of the work of previous investigators, the author describes the results of research work on gun tubes of nickel-chrome steel. The white flakes on the fractured surface of a nickel-chrome steel are the surfaces of hair cracks with the grain differing from the grain of the surrounding surface of the fracture, and the white appearance is due to the different reflection of light. Crystal segregation is the cause of the flakes or hair cracks; the cracks are found in that portion of the alloy which is the last to solidify between the dendritic branches, which portion in consequence of its higher content of alloy elements is cooled with a martensitic structure, whereas

the portion which has solidified first is pearlitic. Flakes may be avoided by the complete dissolution and regular distribution of the ferro-chromium in the bath. This may be promoted by high temperature of the bath, sufficient time to allow thorough dissolution, stirring of the bath, and destruction of the carbides of the ferro-chromium by melting with ferro-silicon before adding it to the bath, the use of low carbon ferro-chromium, the hastening of freezing by casting small ingots, and by casting at as low a temperature as possible. The ingots on cooling down should cool as slowly as possible through the critical temperature range or the ingots should be stripped, soaked, and forged before reaching the temperature of the critical range.

E. Maurer, *Note on Vanadium Steels* (Stahl und Eisen, Sept. 24, 1925, vol. 45, pp. 1629-1632). By the addition of 1.13 per cent. vanadium to a pure carbon steel with 0.74 per cent. carbon, the specific resistance is lowered from 0.168 to 0.146 ohm. If the vanadium percentage is increased to 2.65 the resistance is still further lowered to 0.138 ohm. On the other hand, if these vanadium percentages are added to a carbon-free iron the specific resistance is increased by 0.045 and 0.106 ohm respectively. In carbon steels iron carbide is present in addition to vanadium carbide, but in non-hardening steels no iron carbide exists, and the whole of whatever carbon is present is fully saturated with vanadium. Physical experiments show that vanadium carbide corresponds with the formula V_4C_3 . Vanadium hardenite does not exist, and also there is no point in vanadium carbide steel corresponding with the pearlite point. Like secondary cementite, vanadium carbide dissolves gradually with rising temperature. The degree of solution depends on the vanadium originally contained in the ground-mass.

E. Maurer, *Note on Vanadium Steels* (Kruppsche Monatshefte, Sept. 1925, vol. 6, pp. 165-169). The author presents a short discussion on the influence of vanadium, its characteristic combinations and its chemical relations with carbon. Contrary to the findings of Arnold and Read (this Journal, 1912, No. I. p. 226) vanadium hardenite does not exist, and there is no point corresponding to the pearlite point.

P. Oberhoffer and L. E. Daweke, *An Improved Differential Dilatometer of the Chevenard Type* (Stahl und Eisen, June 4, 1925, vol. 45, pp. 887-890). A complete description, with illustrations, is given of the Chevenard differential dilatometer, and certain improvements in design are indicated with a view to the easier manipulation of the instrument.

L. E. Daweke, *Investigation of the Changes of Length of Carbon Steels* (Stahl und Eisen, May 21, 1925, vol. 45, pp. 786-788). A series of steels with carbon rising from 0.06 to 1.75 per cent., were experimented upon. The contraction occurring at 720° C. on heating, and the corresponding expansion on cooling were measured with a differential dilatometer, and the results are plotted in the form of curves.

Another diagram shows the extent to which the changes in length are affected by the carbon content.

P. Chevenard and A. Portevin, *Results Obtained in the Study of the Expansion of Cast Iron* (Comptes Rendus, 1925, vol. 180, pp. 1492-1495). The study of the expansion of cast iron by means of the differential dilatometer gives an insight into the complex transformations which occur during heating and cooling, and constitutes a better and more complete method of analysis than the thermal method for phenomena occurring in solids. The dilatometer shows that manganese and chromium cause a regression of the Curie point practically proportional to the manganese and chromium contents, showing that manganese and chromium carbides form a solid solution with cementite, and the term "complex cementites" should be used instead of "double carbides." The globular form assumed by certain complex cementites in special steels is not characteristic, but is due to the effect of the special elements on the coalescence of the cementite. Variations in the concentration of cementite can be studied by means of the position of the Curie point, which allows of ascertaining variations in the partition coefficient of manganese between the carbide and ferrite according to the annealing temperature, the Curie point regressing with increase in annealing temperature.

P. Chevenard and A. Portevin, *The Dilatometric Analysis of Alloys* (Revue de Métallurgie, Mémoires, June 1925, vol. 22, pp. 357-373). Apart from chemical analysis, the principal methods of metallography comprise micrography and thermal analysis. Of the latter, the dilatometric method is the most sensitive, the most convenient and the most accurate. The technique and appliances required are briefly discussed, and the subject considered in further detail under the heads: dilatometric characters of the constituents of cast iron; the graphitisation of cementite; commercial types of pig iron; general advantages and conclusions. Dilatometric results are not only qualitative; they may likewise be quantitative. They are, moreover, superior to the ordinary results of thermal analysis, and can be used with the greatest advantage in research.

C. Benedicks and P. Sederholm, *The Anomaly of the Expansion of Invar* (Arkiv för Matematik, Astronomi och Fysik, Jan. 1925, vol. 19, 6 pp.). Invar is not, as hitherto supposed, a homogeneous alloy. It contains a phase α , richer in iron in a state of great dispersion within the principal mass, and a phase γ , which is richer in nickel. Observations show that the coefficient of expansion of invar lies between the limits 0.22×10^{-6} and 0.82×10^{-6} . Certain new peculiarities concerning the expansion properties have been noted, and a theory of the anomaly of expansion of invar has been established.

Magnetic Properties of Iron and Steel.—J. H. Partridge, *The Magnetic and Electrical Properties of Cast Iron* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 191-220).

H. O'Neill, *The Magnetic Properties of Cast Iron* (Electrician, Aug. 7, 1925, vol. 95, pp. 152 and 155). Discusses the magnetic properties of cast iron and their variation with the composition of the iron and the heat or other treatment it may have received. The author concludes that if for any reason cast iron must be used instead of steel in a piece of apparatus it will behave correctly "magnetically," provided its composition is correct and it has been suitably heat-treated.

P. Nicolau, *Contribution to Thermo-Magnetic Analysis; An Induction Balance of Extreme Sensitivity* (Revue de Métallurgie, Mémoires, May 1925, pp. 273-290). Thermo-magnetic methods constitute valuable means of inquiry and sources of information in regard to the constitution, allotropic transformations, and chemical reactions of ferro-magnetic metals and alloys. The present investigations bore on (1) the influence of the magnetising field on the variations in magnetisation with temperature, and more especially on the direction and amplitude of the cementite anomaly, and (2) on the influence of annealing on the latter. A piano-wire containing 0.62 per cent. of carbon was employed for the experiments. The apparatus employed is described and illustrated, and the following conclusions were drawn from the results observed:

Two anomalies occur, one in the neighbourhood of the ordinary temperature, the cause of which is obscure, but which resembles the anomaly observed by Robin, and the other a little above $200^{\circ}\text{C}.$, which corresponds with the loss of ferro-magnetism in cementite at $210^{\circ}\text{C}.$, discovered by Wologdine. These two anomalies manifest themselves in weak or medium fields by a diminution in the magnetic intensity of the wire, but in powerful fields by an increase in the magnetic intensity. In each case there is a definite value of field in which the change takes place, independent of the chemical composition of the sample. There appears to be (1) a progressive reconstitution of the cementite on annealing up to $400^{\circ}\text{C}.$, by the combination of α -iron and carbon, which in the state of solid solution constitutes martensite, and (2) a progressive decomposition of the cementite on annealing, while the steel presents a sorbitic structure.

R. L. Sanford, *Magnetic Analysis needs more Study* (Iron Trade Review, Sept. 3, 1925, vol. 77, pp. 555-559, 595). A discussion of the problems involved in the magnetic study of iron and steel.

P. Nicolau, *The Influence of Quenching and Annealing on the Electromotive and Thermo-Electric Properties of Certain Steels* (Revue de Métallurgie, Mémoires, Aug. 1925, vol. 22, pp. 539-544). The results of a number of experiments on steel of various grades, and on chromium, nickel, chromium-nickel, and silico-manganese steels are tabulated, a description of the methods employed being given, with diagrams and illustrations. They can be made to yield valuable indications, not only as to the properties sought in the actual instances, but to check the readings of Brinell hardness tests, and of tensile tests.

J. Gallibourg, *The Thermo-Electricity of Metals and Alloys* (Revue de Métallurgie, Mémoires, July, Aug. 1925, vol. 22, pp. 400-434, 527-538). After a short chronological review of the chief stages in the development of the knowledge of thermo-electricity, the theory of the subject is described, beginning with an explanation and definitions of the Seebeck and Peltier effects, and those known respectively as the Thomson and the Benedicks effects, illustrated by mathematical formulæ. The principles are then applied to explain the behaviour of thermocouples generally, and the technique of the different methods by which the principles involved can be employed in the investigation of the properties and structure of metals and alloys. In this connection the Haughton, Belloc, and Chevenard methods are dealt with separately, and actual curves relating to iron and its alloys given. The materials of which the heating and cooling curves are investigated comprise a sample of nichrome; a soft steel with 0.09 carbon, 0.08 silicon, and 0.09 per cent. nickel; a semi-soft steel with 0.33 per cent. of carbon, and a hard 0.82 per cent. carbon steel. Several alloy steels, one being an austenitic 24 per cent. nickel steel, and another a manganese-silicon steel are also illustrated. Considerable space is devoted to the Boudouard method of ascertaining the transformation points of nickel steels, and to the Perrier-Wolfers method for plotting differential thermal curves. The Burgess and Scott method is also described. The application of thermo-electric devices for classifying certain alloys in works and for laboratory purposes is described in the concluding section.

J. Young, *Thomson Effect in Iron and Steel Wires* (Proceedings of the Physical Society, 1925, vol. 37, pp. 145-157). Experiments on annealed wires at temperatures ranging from 40° to 300° show that the Thomson effect increases with the carbon content. It decreases regularly with the rise of temperature up to 200°, in which region it becomes irregular and passes through a minimum value. The effect differs according to the direction of the current in respect to the temperature gradient.

R. L. Sanford, W. L. Cheney, and J. M. Barry, *Effect of Wear on the Magnetic Properties and Tensile Strength of Steel Wire* (United States Bureau of Standards, 1925, Scientific Paper No. 510). The report describes an investigation carried out to determine the effect of reduction of area by wear upon the magnetic properties and tensile strength of steel wire of the type used in the manufacture of wire rope. It was found that wear increases the magnetic permeability for low values of magnetising force and decreases it for higher forces. This effect is similar to the effect of tensile stress, though much less in magnitude. The results indicate an increase in tensile strength per unit area with reduction in area, amounting to about 7 per cent. for a reduction in area of 50 per cent. It is concluded that the effect of wear on magnetic properties is due to a redistribution of internal stress. As a result of this redistribution a greater proportion of the remaining

material becomes effective, thus accounting for the observed increase in tensile strength.

W. E. Ruder, *Magnetisation and Crystal Orientation* (Transactions of the American Society for Steel Treating, July 1925, vol. 8, pp. 23-29). Single crystals of silicon steel of varying orientation were tested for magnetic permeability. Wide variations were found between the magnetisation of the strips depending upon their crystal orientation with respect to the direction of impressed magnetic field. The permeability of crystals having their cube edges perpendicular and parallel to the direction of the applied flux was from ten to twenty-five times that of crystals having their cube edges at an angle. The lowest magnetic permeability was obtained when all edges were at 45° with the direction of flux. Curves and photomicrographs are given showing the change and magnetisation as the orientation changes. Over one hundred samples were examined.

E. A. Watson, *The Economic Aspect of the Utilisation of Permanent Magnets in Electrical Apparatus* (Journal of the Institution of Electrical Engineers, Aug. 1925, vol. 63, pp. 822-834). The principal types of steel available for the production of permanent magnets are chrome steels, tungsten steels, cobalt-chrome, and cobalt steels. The cost of these steels is considered, and it is shown that under certain conditions the use of a cobalt steel will prove an economy over a tungsten or a chrome steel, while under other conditions the reverse is the case. The most economical percentage of cobalt would appear to be about 15 per cent. The price of cobalt is the dominant factor, and if it could be supplied at 5s. or 6s. per lb., cobalt steels would undoubtedly supersede chromium and tungsten steels. Some typical examples of the applications of permanent magnets and particularly of cobalt steel magnets are considered.

R. P. De Vries, *Characteristics of Permanent Magnet Steel, with Special Reference to Radio Requirements* (Transactions of the American Society for Steel Treating, Aug. 1925, vol. 8, pp. 139-149). It is pointed out that it is not desirable in the standardised manufacturing processes to vary hardening operations as applied to magnet steel. It is necessary that steel for radio purposes should respond to the one established practice of hardening.

P. Oberhoffer and O. Ernicke, *Chrome Steel for Permanent Magnets* (Stahl und Eisen, Apr. 9, 1925, vol. 45, pp. 537-540). Chrome steel ingots of 220 kilogrammes and 100 kilogrammes weight were examined with a view to ascertaining the effect of ingot size on segregation and the primary structure. The larger ingots showed a greater degree of homogeneity and purity. The effect of segregation was removed by heating for twenty hours at 1150° to 1200° C., without affecting the strength or the magnetic properties. Reheating for a short time and rolling at a moderate temperature had a favourable effect on the material. As the hardening temperature was increased, the magnetic properties tended to rise to a maximum and then decline. This maximum was

dependent on the duration of heating, the quenching temperature, and rate of quenching. With increasing annealing temperatures, the remanence increased and the coercive force fell off, the change being most marked between 250° and 350° C. The product $B_R \cdot H_c \cdot 10^3$ remained constant up to 100° and then slowly fell. Mechanical stressing brought about changes in the magnetic properties, but no fixed law governing these changes could be determined.

J. Würschmidt, *Permanent Magnets* (Elektrische Nachrichten, Jan. 1925, vol. 2, pp. 20-26). The kinds of steel suitable for the manufacture of permanent magnets are discussed, and numerous diagrams are presented showing the characteristics of various chromium, cobalt, tungsten, and other steel alloys.

J. Würschmidt, *The Magnetic Properties of Nickel Steels* (Kruppsche Monatshefte, Sept. 1925, vol. 6, pp. 182-184). The work of previous investigators of the magnetic properties of nickel steels is reviewed.

R. Ruer and K. Bode, *The Magnetic Transformations of Ferro-Magnetic Metals* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1184-1189). In pure electrolytic iron there occurs at 769° both in the heating and the cooling curves a clearly marked arrest point, which furnishes evidence of a polymorphous change at this temperature, that is, the existence at the critical temperature of 769° of two phases differing from each other in heat content. In view of the fact that other ferro-magnetic metals, nickel and cobalt, behave similarly, it must be concluded that in their case also the transformation is a truly polymorphous one. Such a transformation is not necessarily associated with a change in the crystal lattice.

Peschard, *Contribution to the Study of Ferro-Nickels* (Revue de Métallurgie, Mémoires, Aug., Sept. 1925, vol. 22, pp. 490-514, 581-611). The ferro-nickels constitute a most important class of alloys both on account of their abnormal dilatational properties and their high magnetic permeability. A summary is first given of the work of previous investigators of the nickel steel series, with reference to their thermal analysis, micrography, dilatation, specific volume, transformations, paramagnetism, magnetostriction, &c., and their specific heat and radiography. The author's own experiments were carried out on carbon-free iron-nickel samples made from specially pure electrolytic iron, and Mond nickel containing 99.89 per cent. of nickel and 0.045 per cent. of carbon, melted together out of contact with air or carbon in a small Ribaud high-frequency induction furnace. The fullest details are given of the experiments and the appliances used. The most important determinations related to the appearance and disappearance of ferro-magnetism, whether related to the Curie point or to points of allotropic transformation.

A number of diagrams are given relating to both the reversible and the irreversible alloys of nickel and iron. The micrographic investigation of the phenomena of solid solution involved leads to the view that the γ state prevails in the case of irreversible steels, which are also

irreversible in the β state, with the possible exception of the alloy with 11 per cent. nickel. In discussing the general question of magnetism the interatomic structure and atomic motions of the alloys are invoked to afford explanations of the facts observed.

W. Del Regno, *Relation between the Elastic Tension and Magnetic Behaviour of Nickel Steels in the Neighbourhood of the Transformation Point* (Atti della Reale Accademia Nazionale dei Lincei, 1924, vol. 33, Part 2, pp. 87–91). With the reversible iron-nickel alloys, invar and platinite, the curve connecting the elastic limit and the temperature changes its direction suddenly at the temperature at which the alloy passes from the ferromagnetic to the paramagnetic state. With the irreversible alloy containing 22 per cent. nickel this change in direction takes place gradually throughout a temperature range within which the alloy is ferromagnetic when the temperature is rising and paramagnetic when it is falling. With alloys of either type the curve changes its direction at the same temperature as does that for nickel itself, which shows an analogous relationship between elastic and magnetic behaviour.

W. Sucksmith, *The Gyro-Magnetic Ratio for Magnetite and Cobalt* (Proceedings of the Royal Society, Series A, Aug. 1, 1925, vol. 108, pp. 638–642). In a previous paper a null method of determining the gyro-magnetic ratio of iron, nickel, and the Heussler alloys was described, and the present paper extends the results to cobalt and magnetite. For details of the method see Sucksmith and Bates, Proceedings of the Royal Society, Series A, 1923, vol. 104, p. 499.

J. W. Fisher, *Some Further Experiments on the Gyro-Magnetic Effect* (Proceedings of the Royal Society, Series A, Sept. 1, 1925, vol. 109, pp. 7–27). The author discusses the mathematics of the subject and describes his apparatus, experiments, and results. Fields rotating at frequencies of 2 to 5×10^4 cycles were produced by valve generators, but no evidence of the effect sought for was obtained, even in fields of over 100 gauss.

Metallography, Crystallography, Constitution.—K. Honda, *On the Formation of Martensite in Carbon Steels* (Science Reports of the Tôhoku Imperial University, 1925, vol. 14, pp. 165–172). The author deals with the A1 transformation as viewed in the light of X-ray analysis, and explains the formation of martensite by quenching. The distribution of the carbon atoms in the martensite has not yet been confirmed by X-ray analysis, but theoretically considered, these atoms cannot approach too near to iron atoms in virtue of the repulsive force coming into play between the two kinds of atoms. The carbon atoms may take positions in the centre of the face of an elementary cube, distributed here and there according to the law of probability. A local distortion of the lattice may of course result. If this view is correct, carbon atoms in the interspace of the lattice cannot produce any interference lines in the X-ray spectrum. The diffusion of the spectral lines

of martensite is explained by the deformation of the space lattice by internal stress undergone by the martensite structure during rapid cooling, there being no need for assuming a very finely dispersed structure in the martensite crystals.

¶K. Honda, *The Nature of Martensite* (Revue de Métallurgie, Mémoires, Feb. 1925, vol. 22, pp. 119-120). The author discusses the radiography and atomic structure of martensite. An attempt is made to explain the cause of the hardness of martensite, based on the atomic relations of its constituent carbon and iron atoms.

N. T. Belaiew, *On the Inner Crystalline Structure of Ferrite and Cementite in Pearlite* (Proceedings of the Royal Society, Series A, June 2, 1925, vol. 108, pp. 295-306). The author, by using magnifications up to 4000 diameters, has succeeded in examining pearlite grains lying close to or in the section of the specimen. This high-power magnification shows up the petal-like shape and curvature of a cementite lamella; the exposed edge is usually "saw-like" and the "steps" are rectangular and point to the occurrence of cleavage through a definite linear unit, about 250-300 $\mu\mu$. Ferrite lamellæ reveal the existence of small "isolated cubes," whose edges appear to be about 250 $\mu\mu$, despite variations in carbon content and in thickness of the lamellæ. The author suggests that every ferrite lamella is built up of very many of these cubes, which are considered to be perfect crystals, similarly but not uniformly orientated. Every pearlite grain is subjected to stresses during and after its formation owing to the change of the iron from the face-centred to the cube-centred lattice, and this sets up the "steps" in the cleavages in the cementite while the ferrite splits up into the little cubes.

E. C. Bain, *The Persistence of Austenite at Elevated Temperatures* (Transactions of the American Society for Steel Treating, July 1925, vol. 8, pp. 14-22). The stronger atomic bonding between unlike atoms, which is necessary for any solid solution, is offered as the cause for the easier retention of austenite in alloy steels. A chart is given showing the temperature range for the release or decomposition of austenite for a variety of steels. The similarity in effect of temperature elevation and cold-work upon austenite is shown, and the unusually rapid hardening of austenitic steels by cold-work is explained by X-ray evidence of the production of alpha-iron in a form resembling martensite. An explanation is offered for the presence in some steels of more austenite when quenched in oil than when quenched in water. It is suggested that the more violent stresses set up by quenching actually deform the austenite grains and cause transformation.

J. A. Mathews, *Retained Austenite* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 299-308).

W. Rosenhain, *Metallography for Engineers* (Metallurgist, July 31, Aug. 28, Sept. 25, 1925, pp. 102-105, 121-124, 136-139). *Metals under Strain*. Elastic strain and plastic strain or deformation are explained, and the difference of their effects noted. Internal structure of metals

and space lattices are dealt with, and the formation of slip-bands during plastic deformation is described and explained by the crystalline character of metals. Metals are ductile because of the simplicity of their molecular arrangement.

Simple process of slip will not cover all the facts : something more is necessary to explain the marked changes in the properties of metals when "cold-worked." The atoms themselves are not at rest on the lattice points, but are in violent thermal agitation, so that some are at any given moment more readily "detached" from their immediate neighbours than are others, for the atoms themselves cannot be considered as capable of sliding over each other without causing at least local disturbances, as they are all held in place by a balanced system of attractive and repulsive forces. This results, when the motion of slip ends, in a number of atoms being unable to fit themselves into their new positions relatively to the lattice, and one would expect to find a layer in which the regular lattice arrangement is considerably disturbed. It is supposed that the disarrangement of this layer, compared to the regularity of the lattice system, is sufficient to hinder or destroy the progress of further slip in these layers. The thickness of this layer appears to vary with the plastic strain produced. Also the removal of atoms from the lattice produces a kind of "rumpling" which has an even greater effect in opposing further slip, that is to say, in causing hardness. In a crystal aggregate the effect is still more marked, because the individual crystals "rumple" their neighbours ; also they each and all tend to set themselves with their crystallographic axes in the direction of elongation, in order to present their surfaces of slip in the most favourable position.

The converse of strain hardening is "annealing" ; new crystals grow out of the distorted elongated grains and build themselves up on unstrained lattices, thus making the metal soft and ductile again.

Impurities in metals are classified by the author into those which do and those which do not enter into the structure of the metal itself, and those which do alloy with the metal are subdivisible into those which form separate microconstituents and those which do not. The effects and behaviour of these types of impurities are considered separately.

L. Cammen, *Principles of Metallurgy of Ferrous Metals for Mechanical Engineers* (Mechanical Engineering, 1925, vol. 47, May, Section 1, June, July, Aug., Sept., Oct., pp. 339-345, 479-484, 559-565, 637-643, 735-742, 832-836). A series of articles forming a course of instruction in the physical and chemical properties of iron and steel, and their uses and methods of manufacture. Copious references are given in a very complete bibliography.

G. Tammann and G. Siebe, *The Linear Speed of Transformation in the Formation of Pearlite* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1202-1205). The observations of Barrett in 1873 on the recalcrescence of a piece of steel wire on cooling through the critical points are referred to. Experiments were made by the authors to determine the linear

speed at which the γ mixed crystals change into pearlite, and for this purpose measurements were made with wires of 1.2 millimetre diameter, with carbon 0.8 and manganese 0.4 per cent. ; the wires were attached at either end to a copper wire, carried through the stoppers of a glass tube and were heated with a current of 25 amperes. The current was then weakened to different strengths, causing different rates of cooling, and the speed at which the division between the bright red and dull red colour moved was measured. At current strengths from 0 to 6 amperes, the speed was 0.85 centimetre per second. Another wire with carbon 0.64 and manganese 0.69 per cent. was measured in a current of hydrogen under a pressure of 10 to 15 millimetres mercury. The highest speed of transformation was 1.2 centimetre per second. When measured in air under the same pressure it was 0.52 centimetre per second. In the case of the measurement in hydrogen the recalcrescence of the wire in the separation of α -iron from the γ mixed crystals could be clearly seen. The speed of transformation appears to increase with increasing manganese content.

K. Honda, *On the Transformations in Pure Iron* (Science Reports of the Tôhoku Imperial University, 1924, vol. 13, pp. 363-371). The author explains the nature of the A2 transformation, showing that a distinct difference exists between the A2 change and the ordinary change of phase.

O. v. Keil and A. Dammann, *Note on the Phase-Diagram of Ferrous Oxide and Silica* (Stahl und Eisen, June 4, 1925, vol. 45, p. 890). The authors refer to the diagram FeO-SiO_2 as plotted by Whiteley and Hallimond (Iron and Steel Institute, Carnegie Scholarship Memoirs, 1925, vol. 14, pp. 163-186), and have recalculated this phase diagram up to 45 per cent. silica, using ferrous oxide (FeO) and silica, as prepared by Kahlbaum.

P. Oberhoffer, K. Daeves, and F. Rapatz, *Checking of the Carbon Solubility Line in Chromium and Tungsten Steels* (Stahl und Eisen, Apr. 17, 1924, vol. 44, pp. 432-435). For the experiments thirteen chrome steels and thirteen tungsten steels were specially made and forged into bars. These were packed in cast iron turnings, and annealed at 1100°C . for twenty-four hours. A consideration of the results is presented, and after plotting the results in the ternary diagram the position of the solubility lines was found not to be as previously determined by Oberhoffer and Daeves, who have already emphasised the importance of the position of the solubility lines in chromium and tungsten steels, and its bearing upon the correct heat treatment of such steels.

Some correspondence by A. Hultgren followed later, which was replied to fully by the authors (Stahl und Eisen, Apr. 16, 1925, vol. 45, pp. 583-587).

K. Honda, *A2 Line in the Equilibrium Diagram of the Iron-Carbon System* (Communication to the Iron and Steel Institute, Sept. 1925: this Journal, pp. 345-348).

M. L. Becker, *Equilibrium at High Temperatures in the Iron-Carbon-Silicon System* (Communication to the Iron and Steel Institute, Sept. 1925: this Journal, pp. 239-252).

L. Grenet, *Notes on the Iron-Nickel and Iron-Cobalt Equilibrium Diagrams* (Communication to the Iron and Steel Institute, Sept. 1925: this Journal, pp. 267-275).

T. Kase, *On the Equilibrium Diagram of the Iron-Carbon-Nickel System* (Science Reports of the Tôhoku Imperial University, 1925, vol. 14, pp. 173-217). The author has studied the equilibrium diagrams of the binary systems iron-nickel and nickel-carbon, and the ternary system iron-carbon-nickel. The A3 transformation of iron is continuously lowered by the addition of nickel, showing temperature lags on heating and cooling, in the case of irreversible nickel steels. A2 and A3 points coincide at about 5 per cent. nickel on cooling, and at about 10 per cent. nickel on heating. The melting point of nickel is gradually lowered by the addition of carbon. Nickel and nickel carbide form an eutectic, its concentration of carbon being 2.22 per cent. and its melting point 1318° C. The solubility of carbon in nickel is about 0.55 per cent. at the eutectic melting point, and about 0.25 per cent. at room temperature. There is no ternary eutectic, but a binary eutectic of a solid solution consisting of iron-nickel and carbon. The combined or dissolved carbon in the ternary alloys at room temperature rapidly decreases at first, and then gradually increases with increase of nickel to about 0.3 per cent. of carbon with 30 per cent. nickel, and afterwards remains almost constant. The existence of cementite in the ternary alloys coincides with the range in which combined carbon exists. With the addition of nickel, the A1 transformation of iron-carbon alloys is lowered, and tends to be unobservable at about 10 per cent. nickel.

E. D. Campbell and J. F. Ross, *The Chromium-Iron Equilibrium in Carbides Recovered from Annealed 2.23 per Cent. Chrome Steels* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 255-265).

K. Tamaru, *On the Equilibrium Diagram of the System Iron-Carbon-Titanium* (Science Reports of the Tôhoku Imperial University, 1925, vol. 14, pp. 25-32). In the ternary alloys of iron-carbon-titanium containing less than 4 per cent. of titanium, no particular phase is found, titanium being contained in ferrite as a solid solution. With an increase of titanium, the carbon content in the eutectic decreases and the temperature rises; consequently the ternary eutectic curve probably runs from the binary eutectic of the iron-carbon system to that of iron-titanium. As the titanium increases, the solubility of the carbon in austenite decreases, and probably tends to zero on the iron-titanium side. Titanium accelerates the graphitisation of carbide in the alloys, the mechanism being probably similar to that in the case of iron-carbon-silicon alloys.

L. Grenet, *On the Return to the Stable State, with Absorption of Heat in Chemical Systems in Process of Cooling* (Revue de Métallurgie,

Mémoires, July 1925, vol. 22, pp. 472-475). The δ phase in pure iron has now acquired the right to be included in the diagrams, and from the work of Curie and of Westgren and Phragmen it appears to be in the same crystallographic state as the α phase. In the iron-carbon diagram the metal is in the α or δ state at 1450°C . If it be quenched suddenly in a liquid from 1350°C . the α or δ phase transforms to γ , with evolution of heat; but if the metal be quenched from 1450°C . the transformation from the α or δ state to γ takes place at 925°C . with absorption of heat. If, from the same temperature, it be quenched in a bath at 850°C ., the iron remains in the stable α state and the two transformations are suppressed. Quenching, whether followed by annealing or not, thus ceases to have a systematic hardening effect, since the cooling transformation and return to the stable state can be definitely suppressed, and not lowered. It would appear that crystalline phases persist better without change of phase, and yet undergo characteristic transformations. It is also worthy of note that, in the iron-cobalt or iron-nickel system, whether the α or the γ phases are involved, there would appear to be, at a temperature neighbouring on the Curie point, an anomaly of solubility of phases the magnetism of which has varied, and which has a relation to the rapid variations of the specific heats. This anomaly corresponds with an important variation in the curves of the equilibrium diagram which may even involve a change in direction. It serves to explain the two inverse transformations of pure iron, and it is possible that such inverse transformations, with a reversion to the γ state on cooling, may occur in steels high in nickel or cobalt. It is possible, likewise, that, seeing the enormous dilatation which accompanies the transformation of high nickel steels on cooling, this transformation is attended with an evolution of heat. If so, and as, in the case of bronzes, there is an instance of a return to the stable equilibrium with heat absorption, the fact is of interest and deserves closer attention.

F. Wever, *The Allotropy of Iron* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1208-1210). After reviewing the development of the current ideas concerning the allotropy of iron, some results of recent studies of the binary systems iron-silicon and iron-tin are presented. These show that the δ modification represents a phase identical with α -iron. Accordingly, there are only two polymorphous phases to be ascribed to elementary iron—a cubic body-centred modification which is stable up to 900° and above 1401° up to the melting point, and a cubic face-centred modification which interrupts the region of existence between 900° and 1401° of the body-centred phase.

C. A. Edwards and L. B. Pfeil, *The Tensile Properties of Single Iron Crystals and the Influence of Crystal Size upon the Tensile Properties of Iron* (Paper read before the Iron and Steel Institute, Sept. 1925; this Journal, pp. 79-110).

C. F. Elam, *The Orientation of Crystals in Metal Test-Pieces Subjected to Small Strains followed by Heat Treatment* (Philosophical

Magazine, Sept. 1925, vol. 50, pp. 517-520). A comparison is made of the orientations of crystals of aluminium, an aluminium-zinc alloy, and iron, formed by the method of straining followed by heat treatment, with the object of ascertaining whether the method of manufacture influences the orientation. The results of the determination of the crystal axes of sixty-four crystals show that the variety of orientation is great, although it is possible that some directions are more favoured than others. The direction of straining does not influence the orientation of the crystals to the extent that was expected.

C. F. Elam, *The Orientation of Crystals Produced by Heating Strained Iron* (Paper read before the Iron and Steel Institute, Sept. 1925: this Journal, pp. 111-112).

J. S. G. Primrose, *A Remarkable Steel Crystal* (Transactions of the American Society for Steel Treating, July 1925, vol. 8, pp. 30-35). Particulars are given of a steel crystal taken from the pipe cavity of a 50-ton ingot. It is believed to be the longest yet found, being 19 inches in length and weighing 3 lbs. The Tschernoff crystal measured over 15 inches in length. The author briefly discusses the theory of the formation of fir-tree crystals of this nature.

W. Rosenhain, *The Inner Structure of Alloys* (Proceedings of the Royal Institution of Great Britain, 1925, vol. 24, Part 2, pp. 361-364). The atomic structure of alloys is discussed. The constituents of alloys are either solid solutions or intermetallic compounds. X-ray examination shows that in most solid solutions the atoms of both metals are arranged indiscriminately on a single lattice. X-ray measurements of lattice constants and density determinations have established the correctness of the substitution hypothesis, although a single exception exists in the case of alloys of iron and carbon. Substitution of atoms causes distortion of the lattice. Lattice distortion by solute atoms also leads to mechanical hardening, the hardening effect and solid solubility being roughly inversely proportional to one another. The effects of lattice distortion on the electrical conductivity of metals, diffusion in solid crystalline metals, and the lattice structure of a number of intermetallic compounds are also dealt with.

W. Rosenhain, *The Inner Structure of Alloys* (Journal of the Royal Society of Arts, Oct. 9, 16, 1925, vol. 73, pp. 1000-1021, 1022-1037). An explanation is given of the lattice structure of pure metals, and the method of its discovery and establishment. The interaction of different kinds of atoms when they are brought together in a single crystal is also dealt with.

A. Sauveur and V. N. Krivobok, *Dendritic Segregation in Iron-Carbon Alloys* (Communication to the Iron and Steel Institute, Sept. 1925: this Journal, pp. 313-318).

I. E. Moulthrop and E. W. Norris, *The X-Ray Examination of Steel Castings* (Mechanical Engineering, May 1925, vol. 47, Section II, pp. 393-399). The X-rays used are generated by the usual type of Coolidge tube, but very high voltages must be used in order to obtain

the necessary penetrative power. The commercial limit at present is about 250,000 volts, which gives a penetration in steel of approximately 3 inches, which may, under favourable circumstances, be extended to 4 inches. This is sufficient for most of the work required, but not for some of the very heavy parts on ultra-high-pressure equipment. X-rays set up secondary radiations in almost all substances, and special care is needed to filter out these indirect radiations to prevent blurring of the radiograph. The process of radiography is sufficiently sensitive to show a variation in thickness of the object examined of 2 per cent., and as the ordinary flaws of commercial castings of importance are equivalent to variations of 10 or 20 per cent. or more, their detection and estimation is possible with a satisfactory degree of accuracy. The work described in the paper was carried out in testing cast steel components that were to work at a pressure of 1200 lbs. of steam. In order to check the X-ray analysis a condemned casting which had shown a large number of characteristic flaws was cut in sections so as to expose them, and comparisons were made of the etched surfaces and the radiographs. Chemical-physical tests were also carried out, and in every case the original interpretation of the radiograph was fully confirmed.

H. Weiss, *Spectrography by X-Rays and Metallography* (Revue de Métallurgie, Mémoires, June, July, 1925, vol. 25, pp. 333-354, 450-459). An illustrated description of the principles and appliances used in the X-ray examination of metals both by the Laue and by the Debye methods is presented, and the researches of the Braggs, Taylor, Westgren, Carpenter, Elam and Wever, and others on crystal structure are briefly described. The details of present-day practice for the investigation of the atomic structure of metals either in crystals or in powder are also explained.

H. Weiss, *The Application of X-Rays to the Study of Alloys* (Proceedings of the Royal Society, Series A, Aug. 1, 1925, vol. 108, pp. 643-654). The paper describes the application of the powder-photograph method to alloys consisting of (a) only one kind of crystal and (b) conglomerates of several kinds of crystal.

H. Weiss, *The Application of X-Ray Spectrography to the Study of Metals* (Revue Général des Sciences, July 15, 1925, vol. 36, pp. 387-404). A review of the advances made in the study of the structure of metals by means of X-rays since 1912.

F. B. Foley, *Amorphous Cement and the Formation of Ferrite in the Light of X-Ray Evidence* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1925). The X-ray seems to show that no amorphous films are formed by cold-working the surface of cold metals; slip interference satisfactorily explains the raising of the elastic limit by cold-working (heretofore explained by the production of amorphous films at planes of slip), and amorphous metal is not essential to the explanation of intercrystalline weakness at high temperatures. The more rational explanation of the formation of a constituent such as ferrite is based on a movement of single atoms.

The author's argument is that ferrite is not formed within the crystals and rejected to the grain boundaries, but forms at the exterior of austenite crystals.

A. St. John, *Steel Castings and X-Rays* (Iron Age, Sept. 24, 1925, vol. 116, pp. 802-804). The author describes preliminary work in the determination of the size of detectable cavities in steel by fluoroscopic examination.

Sir Robert A. Hadfield, T. G. Elliott, and G. B. Willey, *The Development of the Use of the Microscope in Steelworks* (Journal of the Royal Microscopical Society, June 1925, pp. 105-132). The paper traces the outlines of the development of the application of the microscope to the study of the internal structure of metals and alloys. Examples drawn from the field of the ferrous metals are set out to illustrate the actual application to works problems. Reference is also made to the use of the microscope in examining refractory materials.

C. Benedicks and B. Sederholm, *Some New Observations on Metallographic Microscopes with High Magnification* (Jernkontorets Annaler, 1925, vol. 80, pp. 337-357). Developments in high-power microscopy are described and micrographs up to a magnification of 3000 are shown.

Pyrometry.—H. Schmidt, *The Spectral Pyrometry of Glowing Bodies* (Mitteilungen a.d. Kaiser-Wilhelm-Institut für Eisenforschung, 1925, vol. 6, No. 7, pp. 61-69). The author works out definitions of temperatures at high ranges based on the laws of heat radiation and on the comparison of the body whose temperature is to be measured with the black-body. A comparison of the intensity and colour of the radiation of any radiating body with the radiation of the black-body shows variations in the temperatures of radiation which may be greater or smaller than the temperature of the radiating body which it is sought to determine.

Automatic Temperature Regulation (Electrical Review, May 29, 1925, vol. 96, pp. 878-879). The Cambridge Instrument Co., Ltd., have developed and patented a system whereby temperatures can be closely controlled by an electrical device. A drawing is given of the control unit, which consists principally of a moving-coil galvanometer of the high resistance milli-voltmeter type, and the apparatus can be set to the particular temperature required. Up to about 800° C. a resistance thermometer measures the temperature under control, and above this a thermocouple is used. An electrically operated valve has been devised so that gas-fired furnaces, &c., may be controlled in the same way.

Rustless Steels.—B. Strauss, *The Rustless Steel V2A and its Application in the Construction of Apparatus* (Kruppsche Monatshefte, Aug. 1925, vol. 6, pp. 149-157). The type of rustless steel known as V2A contains about 20 per cent. chromium, 7 per cent. nickel, and 0.20 per cent. carbon. In the ordinary rustless steels with 13 to 15 per cent. chromium the carbon is contained in the form of carbides, and the

structure of these steels always consists therefore of a ground-mass of chromium ferrite with more or less finely divided chromium pearlite interspersed, which, if a small quantity of nickel be added, assumes a troostitic character. The V2A steel, however, has an austenitic structure consisting of single mixed crystals only, in which carbon, chromium, and nickel are completely dissolved. It is a highly plastic alloy, with good tensile properties and high resistance to chemical attack. Owing to its particular structure the V2A steel requires a special heat treatment and care in hot-working. The treatment followed is a sudden quenching from 1170° C., after which the alloy acquires a great degree of softness, toughness, and resistance to acids. It does not harden on cold-working and is completely non-magnetic. Its high ductility (elongation = 50 per cent.) permits of pressing or drawing it cold into vessels of different form to serve as chemical apparatus, and a large number of such apparatus are illustrated.

W. A. Roth, *The Krupp V2A Steel as a Substitute for Platinum* (Kruppsche Monatshefte, Aug. 1925, vol. 6, pp. 157-161). The material as above described is also applicable in the manufacture of instruments and appliances for which platinum is generally used. Such applications are illustrated and described:

B. Strauss, *The Electrochemical Behaviour of Rustless Steels* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1198-1202). The theory of surface oxygen as the cause of passivity has been examined, and the author claims to have disproved Borchers's conclusion that the passivity of a metal is due to the oxygen content. For his experiments he used polished plates of nickel, a nickel-chrome alloy with 78 per cent. nickel and 20 per cent. chromium and non-rusting nickel-chrome steel with 20 per cent. chromium and 8 per cent. nickel. Depassifying was in all cases carried out in 300 cubic centimetres of a 1 : 4 sulphuric acid solution, in which the specimens were immersed for one minute. The potential was measured in a standard ferrous-sulphate solution and two totally different potential values were obtained; the one was about - 0.6, the other about + 0.2 volt. The proportion of chromium producing passivity could not be exactly estimated, as the potential was influenced to some extent by heat treatment and the nature of the surface, but it was about 14 to 15 per cent. chromium. With increasing carbon the amount of chromium required to produce passivity also rose, 0.8 per cent. carbon being sufficient to prevent a 15 per cent. chromium steel alloy from being permanently passive.

H. Esselbach, *Manufacture and Applications of Rustless Iron* (Giesserei Zeitung, June 1, 1925, vol. 22, pp. 317-321). The article describes briefly the manufacture of rustless iron and steel, with special reference to the Hamilton-Evans process in which carbon-free ferro-silicon is thoroughly mixed with 50 per cent. chrome ore and added to the slag of a molten bath of steel in the electric furnace. The compositions of soft chrome steels with 0.1 per cent.

of carbon are given, and the properties, methods of heat treatment, and applications of rustless steels are described.

P. A. E. Armstrong, *Stainless or Rustless Iron Correctly Described as Stable Surface Iron* (Transactions of the American Society for Steel Treating, Aug. 1925, vol. 8, pp. 163-189). A discussion of the characteristics and properties of stainless iron.

J. K. Wood, *Heat Treatment of Non-Corrosive Steels* (American Machinist (European Edition), May 30, 1925, vol. 62, pp. 567-570). The author explains the process of corrosion by the electrolytic theory, and he points out that, besides different atoms having different tendencies to go into solution, similar atoms if differently stressed may exhibit this difference, thus setting up the corrosive galvanic action. The product of corrosion of iron and steel is electro-negative to the metal and consequently accelerates the corrosion when once it has started.

When chromium is added to steel, it forms a solid solution with the iron, so lessening the tendency of the iron to go into solution. Sufficient chromium in an iron alloy will reduce its corrodibility to zero. All the chromium added does not, however, go to the making of the iron-chromium solid solution, but some is locked up in any carbides present, so that the higher the carbide content the greater the amount of chromium necessary to confer immunity from corrosion. On the other hand, suitable heat treatment will reduce the carbide content by inducing a fine martensitic structure, and that will leave more chromium available to protect the iron. The action of chromium is to cause the eutectoid point to occur at a lower percentage of carbon; thus with no chromium the eutectoid carries 0.85 per cent. carbon, but with 4 per cent. chromium the eutectoid carries only 0.56 per cent. carbon and with 12 per cent. chromium it carries only 0.31 per cent. carbon. From this can be seen that much less carbon is needed to produce the various structural changes in steel when chromium is present. The author shows diagrammatically that the stainless steels (chromium 11-14 per cent., carbon 0.25-0.50 per cent.) are pearlitic after slow cooling and martensitic after heat treatment, quench, or air-cooling. Chromium causes a lag in the re-solution of the carbides when the Ac point has been reached on heating up, and this necessitates raising the temperature about 200° C. above the critical temperature to 1000° C.; on quenching from this temperature all visible carbides are eliminated and a pure martensitic structure results. It should be noted here that the Ac point of a 0.3 per cent. carbon stainless steel is about 800° C., instead of the 700° C. for an ordinary 0.85 per cent. carbon steel. The Brinell number of such a chromium steel is about 500 and depends on the quenching temperature and rate of cooling, and the author indicates how these two factors are related. When undergoing tempering stainless steel maintains its hardness up to about 500° C., but it drops suddenly above that temperature. The

advantage of the former fact is that it allows of the internal stress in the metal to be relieved without decreasing the physical properties of the metal or its resistance to corrosion.

Stainless iron (less than 0.1 per cent. carbon) has certain advantages over stainless steel. It is less hard, but is much safer to heat-treat, easier to machine, and less corrodible, owing to its lower carbon content, making it less susceptible to varying heat treatment.

In America stainless steel is made with 0.6 per cent. carbon and 12–14 per cent. chromium. It is hardened in oil from 1000° C. and tempered at about 250° C., resulting in a tensile strength of 205,000 lbs. per square inch (higher than British practice), yield point 100,000, elongation 9.0 per cent., and reduction of area 25.0 per cent. (these three lower than British practice).

Other stainless steels are produced by alloying certain other metals to a chromium-steel basis and their distinguishing characteristics are briefly noted.

J. M. Quinn, *Making Cast Stainless Steel* (Iron Trade Review, July 23, 1925, vol. 77, pp. 185–188, 225). Electric furnace practice for the production of stainless steel as carried out in an American plant is described. Detailed costs of the process are given.

Corrosion.—G. M. Enos, *Fundamental Factors in Corrosion* (Industrial and Engineering Chemistry, Aug. 1925, vol. 17, pp. 793–797). The author explains the mechanism of corrosion by the electronic theory of the constitution of matter. Corrosion starts with the loss of electrons from the metal undergoing corrosion and their gain by the corroding medium. Ten factors controlling the progress of corrosion are enumerated but only four are studied, namely, the chemical composition of the alloy, the effect of increase of temperature, the time of exposure, and the effect of light. The author's experiments on a variety of steels, with carbon from 0.01 to 1.2 per cent., lead him to think that there is no marked superiority of any one kind over the others. The effect of a rise in temperature is in general to accelerate the corrosion, but distilled water appears to show a maximum about 73° C. Increase of time appears to have a greater effect when the specimens are suspended in the atmosphere than when submerged in distilled water. The effect of daylight appears to be not very great; ultra-violet light has a marked accelerating effect.

E. Blough, *The Evolution of Corrosion Tests* (Paper read before the American Society for Testing Materials, June, 1925). In addition to the loss of weight of a corroded sample, and the depth of pitting, a third test is of great value, namely, the loss of strength and ductility. This shows the effect of corrosion on the residual and apparently unattached metal.

J. H. Whiteley and A. F. Hallimond, *The Reactions of Plain Carbon Steels with Nitric Acid* (Iron and Steel Institute, Carnegie

Scholarship Memoirs, 1925, vol. 14, pp. 163–186). This investigation is a continuation of a previous one by the same authors on the chemical detection of strain in iron and steel (Carnegie Scholarship Memoirs, 1918, vol. 9, pp. 1–58). The results given demonstrate that the reactions of iron and steel with nitric acid under certain defined conditions are capable of yielding valuable information on the relative amounts of energy retained by the metal after various treatments. The reaction curves of quenched steels point to a high energy content, and its gradual decrease on tempering as indicated by the curves is traced.

R. Girard, *Action of Dilute Acid Solutions on Ferrous Metals* (Comptes Rendus, 1925, vol. 181, pp. 215–218). Polished steel and cast iron plates were exposed to attack by solutions of sulphuric, hydrochloric, and carbonic acids, also of phenol, all of concentrations lower than $N/10$. The amount of corrosion was determined by measuring the amount of iron passing into solution after immersion of the plates for forty-eight hours. For a given acid the two metals were about equally attacked, but with rough surfaces the steel was the more readily attacked. With exceedingly dilute acids the amount of corrosion was independent of the nature of the acid and its concentration; and it remained constant for a given dissolved oxygen content.

Delbart, *Corrosion of Cold-Drawn Steels by Varying Concentrations of Sulphuric Acid* (Comptes Rendus, 1925, vol. 180, pp. 1942–1943). Five steels, three ranging from soft to hard carbon steels, one manganese and one silicon steel, were subjected to attack by 2 per cent. sulphuric acid, 98 per cent. sulphuric acid, 20 per cent. oleum, and 60 per cent. oleum. The corrosion decreased steadily as the concentration of acid increased, but it increased with 20 per cent. oleum and again decreased to a minimum in 60 per cent. oleum. The corrosion in dilute acid was least and in 20 per cent. oleum greatest after annealing at 700° , except in the case of the silicon steel.

Y. Utida and M. Saitô, *The Influence of Metallic Elements on the Corrosion of Iron and Steel* (Science Reports of the Tôhoku Imperial University, 1925, vol. 14, pp. 295–312). The influence of various metallic elements on the corrosion of iron in nitric, hydrochloric, and sulphuric acids, and atmospheric oxygen at 1100° C. was studied.

O. Bauer, *Behaviour of Iron, Bronze, and Brass in Salt Waters at Ordinary Temperatures and at Temperatures and Pressures usual in Steam Boilers* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1101–1109). For the experiments the metal specimens were in the form of small plates. Corrosion tests at ordinary temperatures were made in solutions of water with chlorides and sulphates of magnesia, chlorides and sulphates of soda, calcium chloride, and with some solutions in which these salts were mixed. Two series of tests were made, one in still and one in running liquid. In still and in running liquid it was found that the corrosive effect of magnesium salts was, if anything, less

than that of sodium and calcium salts, and in any case with the solutions chosen, ranging in each case from 0.068 to about 1.9 grammes of salt per litre of distilled water, it was concluded that magnesium salts do not dangerously attack iron. The experiments in steam boilers were made at a steam pressure of 16 atmospheres, and the same salt solutions were employed. The chlorides and sulphates of soda and calcium had no effect, and neither the iron, bronze, nor brass plates were attacked, but the magnesium salt solutions attacked the iron strongly and corrosion was the more rapid as the strength of the solution was increased. The explanation is that a hydrolytic splitting up of the magnesium salts occurs at high temperatures and pressures, while the sodium and calcium salts undergo no such splitting up.

C. H. S. Tupholme, *Corrosion by City Gas* (Iron Age, Sept. 17, 1925, vol. 116, p. 738). Brief particulars are given of the results of an investigation carried out by two British gas manufacturing concerns to determine the effect of town gas on the corrosion of various brands of wrought iron pipe. The tests show that carbon dioxide is not an essential agent for oxidation, though its presence to about 2.5 per cent. in a wet gas containing 1 per cent. of oxygen would probably accelerate the rate of oxidation by about 10 per cent. assuming that liquid water is present. Though carbon dioxide does not form an oxide of iron, it does, in the presence of water, slowly remove iron in the form of a solution of ferrous bicarbonate, and this soluble compound in the presence of oxygen forms an oxide which is readily transportable, and would lead to the stoppage of small pipes. There is no evidence in ordinary gas-distributing systems of products of corrosion that have any retarding effect upon further corrosion. The tests also disclose an astonishing variation in the composition of wrought iron gas pipes, and also the fact that tubing sold as wrought iron is, in many cases, a mixture of iron and steel.

Corrosion and Rusting of Wrought Iron and Steel Gas Barrel (Gas Journal, July 22, 1925, vol. 171, Supplement, pp. 3-13). A report of the Institution of Gas Engineers Wrought Iron Tubing Inquiry Committee is published, containing the results of their investigations of the corrosion of iron and steel gas barrel of post-war and pre-war manufacture. The work was carried out by the South Metropolitan Gas Company and the Gas Light and Coke Company.

R. V. A. Mills, *Protection of Oil and Gas Field Equipment Against Corrosion* (United States Bureau of Mines, 1925, Bulletin 233). The paper contains a detailed discussion of the causes and effects of corrosion of equipment used in oil and gas fields, and outlines methods for abating the trouble. Practically all the corrosion dealt with is of galvanic origin.

F. F. Fowle, *Accelerated Corrosion Tests on Bare Overhead Electric Conductors* (Paper read before the American Society for Testing Materials, June 1925).

A. Portevin, *The Corrosion-Cracking of Steel under the Influence of*

Internal Stresses (Revue de Métallurgie, Mémoires, Mar. 1925, vol. 22, pp. 179-190). Very little work has been done on the corrosion cracking of steel, but during the war stocks of shells filled with "vincennite," a mixture of hydrocyanic acid, tin and arsenic chlorides, and chloroform showed, some four to ten months after filling, cracks in the region of the band, accompanied by a sweating out of the filling, and their resistance to hydraulic pressure fell very considerably. On sectioning the shell radial cracks could be seen in the walls of the metal. On fracture the surfaces of fracture were found to be blackened by the action of the mixture. A number of researches carried out on such steels established the following conclusions:

1. Every permanent deformation of a hollow cylinder sets up in its walls internal stresses which act as tensile strains in the interior of the walls.

2. The operation of banding provokes permanent deformations in the shell in the region of the walls adjoining the banded zone, and by work-hardening the metal sets up stresses.

3. The effect of these considerations explains, indirectly, the origin of the cracks. This explanation finds confirmation in the results of experiments on cracks induced in the same way by pickling banded shells. The physics of the stresses thus induced are discussed and illustrated by diagrams, and their intensities estimated mathematically, in an appendix, as well as the conditions of stress which occur when shells are machined and grooved for receiving the driving band. A method of minimising such stresses by adjusting the heat treatment conditions is suggested.

H. Beeny, *An Electrochemical Method for Estimating the Corrosion of Iron and Steel* (Paper read before the American Electrochemical Society, Sept. 1925). Tests were undertaken to determine the influence of manganese on the corrosion of hypo-eutectoid steel. An apparatus was devised, using a gold cathode with an immersed surface forty times that of the polished steel specimen which was made the anode. The electrolyte was a 0.2 per cent. sodium chloride solution. Manganese sulphide appeared to stimulate local corrosion. Manganese as carbide, and in solid solution, had little or no effect upon the corrodibility of the metal. Experiments were also made to determine the effect of varying the quantity of air (oxygen) in solution upon the rate of corrosion. The results indicated that the purely chemical effect either did not exist at all or was extremely slow and unimportant compared with the electrochemical reaction.

R. Stumper, *The Chemical Composition of Rust* (Chimie et Industrie, June 1925, vol. 13, pp. 906-910). The author shows by means of tables that the composition of rust is variable between wide limits, and he concludes that rust is a substance to which no chemical formula can be assigned, but is either a simple mixture of FeO , Fe_2O_3 , and H_2O , or else a solid solution of FeO in Fe_2O_3 more or less hydrated. The author notes that some FeO is always present in rust whether

newly formed or of ancient origin. He conducted experiments in which he determined the amount of FeO and Fe_2O_3 formed by the rusting of steel plates in tap water during varying periods. He plotted on a graph the percentage of FeO in the rust produced. The result was approximately a hyperbola, and as the time was reduced to zero, so the curve tended to reach the value 100 per cent. The author concludes from this that FeO is the first product of oxidation in the formation of rust, and that the subsequently formed Fe_2O_3 encloses some FeO and shields it from complete conversion into Fe_2O_3 .

C. Jakeman, *Tests of some Rust-preventing Materials Suitable for the Protection of Machinery* (Engineering, July 31, 1925, vol. 120, pp. 123-125). Tests on the protection afforded by the following materials were made: lanoline deposited from a solution, also rubbed on as a grease, a mixture of petroleum grease and varnish material with red colouring matter, another varnish in a paraffin solvent coloured blue, bitumen in naphtha, a mixture of resin, resin spirit, Dammar gum and dehydrated methylated spirit (made to the analysis of a German preparation), and petroleum jelly. Tests were carried out in four ways: Exposure to air and rain, and direct sun also; exposure by submersion in distilled water with aeration; exposure by submersion in sea-water with aeration; exposure to tap water at 150°F . aerated by bubbling air into the vessel; the test-pieces were mostly built up of half gun-metal and half steel, and the electrolytic action at the joint was observable.

The author's results are fully tabulated, but it may be noted that preservatives of a greasy nature gave better results than hardening paints or varnishes, and that lanoline showed a very great adherence to metal even at a raised temperature.

Electro-Plating, Galvanising, and Coating.—E. A. Ollard, *The Resistance to Corrosion of Electro-Deposited Chromium* (Paper read before the British Association, Aug. 27, 1925: Iron and Coal Trades Review, Sept. 4, 1925, vol. 111, p. 361). The author has investigated the properties of chromium-plated material and a comparison is made with other plating processes. Steel test-pieces were plated by Liebreich's process, in groups of nine, with different metals and different combinations. Of these groups, three were exposed to atmospheric corrosion, three were exposed to the action of steam, and two were placed in salt sprays, while the remaining one was heated in the presence of air. The author concludes that chromium plating is especially suitable in cases where an article is required to keep bright without cleaning. The chromium, being hard, takes a very high polish, and in this condition it appears to resist corrosion even better than in the unpolished state. Chromium, however, is liable to be porous when deposited in thin coatings, and for this reason a single layer of such a coating does not form an efficient protection to an easily corrodible material such as steel.

The results of the tests seem to indicate that the most satisfactory plating for all-round purposes is the chromium plating made with nickel

as an underlying metal. Steel plated first with cadmium and then with chromium appears to stand very well against atmospheric corrosion, but the chromium has a very strong tendency to strip from the cadmium. Also, chromium plated on cadmium will not take a high polish. Unless these difficulties can be overcome, therefore, it seems unlikely that cadmium will prove a satisfactory metal for underlying chromium. An important application for chromium plating has been in the protection of die-casting moulds.

G. M. Enos, *The Plating of Chromium on Steel* (Transactions of American Electrochemical Society, 1925, vol. 48; Engineer, Aug. 21, 1925, vol. 140, p. 188). Steel can be plated with chromium by the methods described by Schwartz, but it is recommended that the temperature of the solution be kept low.

For periods up to six hours, and temperatures up to 1050°C. , no combination of chromium plating, heat-treating for diffusion and case-hardening, could be found to give surfaces that would be hard and at the same time resistant to corrosion. Chromium plate on steel prevents cementation under the ordinary time and temperature conditions employed in case-hardening. Salkover's bath containing 30 per cent. CrO_3 and 1 per cent. $\text{Cr}_2(\text{SO}_4)_3$, worked with a current density of 0.8 to 1.0 ampere per square inch (12.8 to 16 amperes per square decimetre), is quoted as giving best results. The CrO_3 concentration may be considerably reduced and the sulphate increased somewhat without harmful results, but as the temperature tends to rise very much the bath must be cooled with running water, or, better still, iced water. The conditions for the production of a chromised surface as found by Kelly, and the behaviour of chromium towards CO and carbon, are noted, but all the author's experiments based on these data failed to give specimens of sufficient hardness or to show sufficient evidence of diffusion of the chromium into the steel to warrant their preparation for corrosion test. The inference is that plated chromium does not absorb carbon—that is to say, it is not cemented to any appreciable extent at the ordinary case-hardening temperatures. Tables are given summarising the various experiments and their results.

H. E. Haring, *Principles and Operating Conditions of Chromium Plating* (Chemical and Metallurgical Engineering, Aug. 1925, vol. 32, pp. 692–694). Experiments were made to find a method of obtaining a hard surface on plates for “plate” or intaglio printing which have to withstand a great deal of abrasion. Until a few years ago all plates used at the Bureau of Engraving and Printing were case-hardened steel, but the electro-deposited chromium surfaces obtained by the author have a scratch hardness even greater than the hardest steel.

The operating conditions used for several months now are :

Solution Composition.	Ounce per Gallon.	Grammes per Litre.
Chromic acid, CrO_3	33.0	250
Chromium sulphate, $\text{Cr}_2(\text{SO}_4)_3$	0.4	3
Chromium carbonate, $\text{Cr}_2\text{O}(\text{CO}_3)_2$	1.0	7
1925—ii.		2 L

The solution is contained in a 40-gallon (150 litre) stoneware jar, which conveniently holds a plate 15 in. \times 18 in. (38 \times 46 cm.). The anodes, four sections of $\frac{3}{4}$ in. (2 cm.) lead pipe, are immersed to a depth of 18 in. (46 cm.), and are suspended about 7 in. (18 cm.) from the face of the plate, giving an anode area of approximately half that of the cathode; no chromium deposits on the back. A lead pipe coil behind the cathode maintains the correct temperature of the bath, which is dependent upon the current density employed. It should be between 40° C. and 50° C., 45° C. being preferable, at which temperature a current density of 100 amperes per square foot (11 amperes per square decimetre) on a steel cathode gives good results.

One point is heavily stressed: when plating on steel, nickel, or similar metals, the current must be switched on before immersing the cathode. The CrO_3 in the bath renders these metals passive, and so causes bad plating. The underlying principles of the plating of chromium in general, and of this method in particular, are stated, including the cause of the passivity of iron, nickel, &c., referred to above. A neat method of stripping the deposited chromium from iron and nickel, and also copper and brass, is given as well.

C. G. Fink, *Chrome Surfaces Electrolytically Deposited* (Forging, Stamping, Heat Treating, June 1925, vol. 11, pp. 202-203). The Chemical Treatment Company of New York have a factory for the production of chromium plate to which they have given the trade name "Crodon," and the article enumerates the many uses to which it may be put.

Chromium Plating—A Warning (Metal Industry, Oct. 9, 1925, vol. 27, pp. 331-332). There is a somewhat prevalent idea that chromium plating is now an established commercial process which anybody can undertake. The fact is chromium plating is still in the experimental stage, and there is yet a great deal to be done before the process can become an ordinary routine matter. Some of the difficulties that have yet to be overcome are described.

C. T. Thomas and W. Blum, *The Protective Value of Nickel Plating* (Paper read before the American Electrochemical Society, Sept. 1925). Samples of sheet steel were nickel-plated under various conditions and subsequently tested by methods which would indicate the relative protective value of the coatings. The plating processes employed in the investigation are enumerated, and the composition of solutions and conditions of plating are tabulated. The nickel-plated samples were subjected to the ferricyanide, intermittent immersion, salt spray, and atmospheric corrosion tests. The results indicate that all nickel coatings are porous, and that the only practical method of reducing the porosity and increasing the protective value of the nickel is by the use of relatively thick coatings, preferably not less than 0.001 inch. Results of scratch hardness tests are included in the paper. The protective value of copper and nickel plating, in which the copper is applied either preliminary to the nickel or as an intermediate layer between an initial and final deposit of nickel, is also tabulated.

J. D. Knox, *Plates Base Metal with Nickel* (Iron Trade Review, July 30, 1925, vol. 77, pp. 247-248, 290). Nickel-plating practice at the plant of the Metal Protection Co., Cleveland, is described. The Madsen process is used, and it is claimed that a nickel coating can be deposited direct on to a steel base without an intermediate coating of copper. A special solution, of which no particulars are given, is used for removing the surface gases of the steel before plating.

C. S. Trewin, *Status of Galvanising Improving* (Iron Trade Review, Aug. 13, 1925, vol. 77, pp. 370-373). The development of the hot galvanising process is outlined, and particulars are given of proposed tests to be carried out by the American Zinc Institute to determine the life of various weights of galvanised coatings under different atmospheric conditions.

J. Cournot, *The Researches of Edwin Dudley Martin Relative to the Coating of Ferrous Alloys by Aluminium* (Revue de Métallurgie, Mémoires, Mar. 1925, vol. 22, pp. 139-153). This is a critical summary and abstract of a thesis presented in November 1924 by E. D. Martin before the Faculty of Sciences at Nancy. In regard to aluminium, the iron-aluminium diagram proposed by Guertler was taken as the basis of the investigations. In using aluminium as a coating for other metals the rate of diffusion, the surface tension of adjacent grains or crystals, and the influence of temperature are the chief considerations. Carbon is insoluble in an iron-aluminium solution. The pearlite of steel therefore resists adhesion to the eutectic and its derivatives. The phenomenon of diffusion is what really determines the adhesiveness of a protective coating. Tinning is not discussed, but sherardisation (zinc coating), calorisation (coating with aluminium), and chromisation, are each considered in turn. A new process, akin to calorisation, is proposed. For its application the simultaneous presence of ammonia and of aluminium salts is necessary. The formation of aluminium chloride at the temperature employed is due to the action of decomposing ammonium chloride, the nascent chlorine being specially active. Iron coated with aluminium by the new process will resist atmospheric attack, but not the action of acid. The coating is strongly adherent and free from cracks or porosity.

Asphaltic Coat Protects Steel Pipe (Iron Trade Review, Aug. 27, 1925, vol. 77, pp. 489-494). The application of asphaltic coatings to steel pipes is briefly dealt with.

E. L. Collis and H. M. Vernon, *A Comparison of Old and New Tinning Processes* (Iron and Coal Trades Review, July 10, 1925, vol. 111, pp. 58-59). The authors report the results of an investigation carried out under the auspices of the National Institute of Industrial Psychology. A number of direct comparisons of the working conditions have been made at a tinplate works where there were three Abercarn pots and three Thomas and Davies tinning machines in operation. The observations were purposely made during hot weather when conditions were likely to be most trying to the

workers. In addition the conditions at another works where the Player pot is used were also studied.

Detinning of Scrap.—*Electrolytic Detinning* (Chemiker Zeitung, 1925, vol. 49, pp. 117–119). The electrolytic method of detinning is described in detail. The material to be treated, generally in the form of tins, is thoroughly cleaned in a strong soda solution. It is then washed with water and pressed into a compact mass by passing through fluted rollers. The detinning operation is carried out in tanks with iron electrodes and circulating electrolyte of 8 per cent. sodium hydroxide. The current density is about 100 amperes per square metre at an electromotive force of 1.5 volts. The temperature is kept at 80°. The tin is oxidised at the anode to an oxyhydrate, which is dissolved by sodium hydroxide to sodium stannate, and this is decomposed at the cathode to form tin sponge and sodium hydroxide. The detinning time is about four hours.

I. Ginsberg, *Recovering Tin from Tin Cans* (Iron Age, Aug. 20, 1925, vol. 116, pp. 473–474). The methods of detinning with the aid of chlorine and detinning in the open-hearth furnace are outlined, and a description is given of the electrolytic process and plant. Its advantages over the other methods are discussed.

Electrolytic Deposition of Iron.—R. Cazaud and R. Hughes, *Contribution to the Study of Electrolytic Iron; the Influence of Annealing on the Mechanical and Magnetic Properties* (Revue de Métallurgie, Mémoires, Apr. 1925, vol. 22, pp. 218–222). A description of investigations carried out at the Conservatoire National des Arts et Métiers. Special precautions are necessary in preparing test-pieces from electrolytic iron owing to its brittleness. Annealed specimens showed a marked change in the hardness when the annealing temperature ranged between 750° C. and 950° C. In this interval it fell considerably, but remained nearly constant when the annealing temperature was raised to 950° C.–1100° C. Permeability tests by the Illovici method showed that at 500° C. considerable alteration in the magnetic properties occurred. In both cases the changes in property were attributed to the escape of hydrogen in the temperature intervals noted. Electrolytic iron contains considerable amounts of occluded gas, chiefly hydrogen, which may amount to 0.006 per cent., by weight, of the material. This hydrogen must either be in a state of combination or complex association. It is this that renders the samples brittle, and the view is put forward that a solid solution of hydrogen-iron is present at the lower temperatures. By melting a sample of “Bévé” iron *in vacuo* the micrographic structure of the metal was found to lend support to this view. It was further found that such material might be contaminated by the presence of lead, which came from the original bath and had been deposited with the iron on the cathode. Such lead would be balled up during annealing, and expelled completely by melting the material *in vacuo*.

Making Pure Iron Commercially (Iron Age, Sept. 10, 1925, vol. 116, pp. 675-678). An illustrated description of the methods and plant used by the Niagara Electrolytic Iron Co., Niagara Falls, for the production of electrolytic iron in the form of tubes. The process and plant used are almost identical with those in operation at Grenoble, France. The French process was described by Guillet in the Journal of the Iron and Steel Institute, 1914, No. II, pp. 66-81.

Laboratories.—*The Heat Treatment of Steels* (Engineering, June 26, 1925, vol. 119, p. 818). This short article gives a very brief note on the new laboratory equipped by Professor J. H. Andrew at the Royal Technical College, Glasgow, for instructing students in the subject of heat treatment.

H. W. Gillett, *Standards Bureau Metal Research* (Iron Age, Aug. 20, 1925, vol. 116, pp. 461-465, 513, 536-542). The author outlines the nature of the research work carried out at the Bureau of Standards, and includes illustrations of the equipment used.

CHEMICAL ANALYSIS.

Analysis of Iron and Steel.—A. E. Cameron, *Determination of Arsenic in Steel* (Industrial and Engineering Chemistry, Sept. 1925, vol. 17, pp. 965–966). The method described is a modification of Mohr's procedure, and is claimed to be shorter and simpler than the usual methods of determination.

A. Terni and A. Amati, *Determination of Silica in Grey Cast Iron* (Giornale Chimica Industriale ed Applicata, May 1925, vol. 7, pp. 255–257). A method is described by which the inconveniences may be obviated which attend the presence of graphite in the silica obtained in the ordinary methods employed for the estimation of silicon in grey cast iron.

A. Mele, *Determination of Phosphorus in Steel and Cast Iron* (Giornale Chimica Industriale ed Applicata, May 1925, vol. 7, pp. 247–253). The author gives the results of investigations on the current methods for determination of phosphorus in iron and steel, both in the presence and in the absence of other elements, such as vanadium, titanium, zirconium, tungsten, and silicon. The methods are tested and the results compared.

P. Oberhoffer, *Oxygen in Iron* (Stahl und Eisen, Aug. 6, 13, 1925, vol. 45, pp. 1341–1348, 1379–1384). The author presents a reasoned discussion based on the work of several previous investigations of the part played by oxygen in the refinement of steel and of the influence of oxygen on the weldability and tensile properties of steel. In particular, reference is made to the work of Rosenhain, Tritton, Hanson and Rooney (this Journal, 1924, No. II. pp. 85–143), and of Oberhoffer and d'Huart and A. Wimmer (Stahl und Eisen, Feb. 13, 1919, vol. 39, p. 165, and Jan. 15, 1925, vol. 45, p. 73). Nevertheless little information is available concerning the influence of oxides other than of those which have been used by the above-mentioned workers for the preparation of synthetically oxidised steel. One obstacle in the way of judging the effect of oxygen in steel has been the difficulty of finding a suitable method for its accurate estimation, and the author gives details of his own procedure in working out a method for determining the total oxygen in steel. After many experiments he obtained good results with Ledebur's method, with the following modifications: he used electrolytic hydrogen, a vacuum pump to remove all the air originally in the apparatus, a quartz tube in which the reaction occurred, and ground-in joints. In order to make the process work at a lower temperature, the filings were melted with one part tin and one part

antimony, and difficultly reducible manganous oxide was completely reduced and silica as iron silicate partly so. The process is quite accurate except when very much manganous oxide is present and when carbon is contained in any quantity, because this latter combines with the oxygen of the oxides and gives CO and CO₂, which are not collected. The "heat extraction" of gases was tried: the filings were melted as before with tin and antimony, and the resulting CO, CO₂, H₂, and N₂ were pumped off and estimated. Here again carbon in the sample caused trouble, because it could not be determined whether the CO and CO₂ were present as such in the sample or whether they were in part due to the combination of carbon with oxide oxygen. He also obtained results with the method of Wüst and Kirpach when suitably modified, using bromine as a solvent, which would leave the oxides undissolved as an "insoluble matter." This process is well adapted to work in a routine laboratory, but it fails when too much carbon as carbide is present, particularly in alloy steels. The author puts forward a suggestion that the process of volatilising the iron in a current of chlorine gas, as is done in the estimation of silica in ferro-silicon, may also be capable of adaptation. A very complete table at the end of the article sets out the results of oxygen estimation obtained by the three methods outlined, and in many cases very close agreement is obtained; where differences occur they may be traced to the higher carbon or manganese contents, as shown in the analyses included in the table.

R. Scherer and P. Oberhoffer, *Estimation of Oxygen in Iron by Analysis of Residues* (Stahl und Eisen, Sept. 10, 1925, vol. 45, pp. 1555-1557).

J. Keutmann and P. Oberhoffer, *Estimation of Oxygen by the Hydrogen Method, with Addition of Tin-Antimony Alloy* (Stahl und Eisen, Sept. 10, 1925, vol. 45, pp. 1557-1559).

H. Strauch and P. Oberhoffer, *Estimation of Oxygen by the Hot Extraction Method* (Stahl und Eisen, Sept. 10, 1925, vol. 45, pp. 1559-1563). These methods for estimation of oxygen have been carefully tested and improved upon, in view of Oberhoffer's previously expressed opinion as to the doubtful accuracy of the methods usually followed. By modifications in the apparatus and in procedures, the authors are satisfied that oxygen determinations can be carried out with extreme accuracy by their improved methods, particularly the hydrogen method.

R. von Seth, *Development of Methods for the Determination of Oxygen in Recent Years* (Jernkontorets Annaler, 1925, vol. 80, pp. 320-331).

A. Kropf, *Determination of Manganese in Special Alloy Steels and Other Ferrous Alloys containing Cobalt* (Chemiker Zeitung, 1925, vol. 49, p. 315). A discussion as to whether the chlorate method for determining manganese is accurate when the manganese content is low, and as to whether it is advisable to add a known amount of manganese.

A. Kropf, *Methods for Determining Manganese in Alloy Steels, with Special Reference to the Silver-Nitrate-Persulphate Method* (Chemiker

Zeitung, 1925, vol. 49, pp. 517-520). The elements tungsten, chromium, molybdenum, vanadium, and cobalt interfere with the determination of manganese in alloy steels. The persulphate method can be modified and applied to the analysis of these steels.

M. L. Nichols and S. R. Cooper, *New Qualitative Test for Copper, Iron, and Cobalt* (Journal of the American Chemical Society, May 1925, vol. 47, pp. 1268-1270). When an aqueous solution of dinitrosoresorcinol is added to a solution of a copper, iron, or cobalt salt, a precipitate or coloration is produced, depending upon the amount of the salt present. In neutral solution this reagent is capable of detecting 0.0040 milligramme of copper, 0.0035 milligramme of iron, and 0.0033 milligramme of cobalt in 1 cubic centimetre of solution, which limits compare favourably with those of the tests used at present for the detection of these metals. In very dilute acid solutions in the presence of sodium acetate the sensitiveness of the tests for cobalt and iron is increased, but not for copper.

W. Hartmann, *Determination of Vanadium* (Zeitschrift für analytische Chemie, 1925, vol. 66, pp. 16-23). The author discusses the various well-known methods for determining vanadium in ferrovanadium. The conclusion is drawn that when the KMnO_4 method is used, the solution should be standardised against a sample of known vanadium content.

F. Fettweis, *Note on the Analysis of Tungsten Steels* (Stahl und Eisen, July 9, 1925, vol. 45, pp. 1109-1110). The author describes attempts to simplify the analysis of tungsten steels by the use of phosphoric acid in the estimation of the various elements contained in the steel, such as chromium, manganese, nickel, and silicon. The experiments showed that no particular advantage was derived from the use of phosphoric acid, and in the case of the manganese determination it was definitely harmful.

T. Nakazono, *Application of Liquid Amalgams to Volumetric Analysis. Part I. Estimation of Molybdenum, Titanium, and Iron*, (Science Reports of the Tôhoku Imperial University, 1925, vol. 14, pp. 109-117). The author describes a method of volumetric analysis in which a liquid zinc amalgam is used.

Analysis of Ores and Refractories.—O. Hackl, *Determination of Ferric Oxide in Insoluble Silicates* (Zeitschrift für anorganische Chemie, 1925, No. 66, pp. 401-430). The silicate is decomposed by hydrofluoric and sulphuric acids, and the iron titrated with a decinormal solution of titanous chloride, using thiocyanate as an internal indicator. Hydrofluoric acid normally prevents the formation of ferric thiocyanate, but this interference is prevented by the addition of a 4 per cent. solution of boric acid at the rate of 150 cubic centimetres for every 10 cubic centimetres of hydrofluoric acid used.

F. Meyer, *Apparatus for the Determination of Ferric Oxide* (Chemiker Zeitung, 1925, vol. 49, p. 622). The sample while dissolving is pre-

vented from contact with air by fitting the flask with a device resembling a small Liebig's condenser. The upper end of the central tube is fitted with a Bunsen valve, just below which, within the outer casing, is a side tube terminating at the bottom of the casing, which is filled with a solution of sodium hydrogen carbonate. Immediately the sample is dissolved and the flask cools some of the solution is drawn back by suction into the flask, and the liberated carbon dioxide serves to prevent the formation of a vacuum in the flask, avoiding the risk of breakage.

Analysis of Refractory Materials (Gas Journal, June 17, 1925, vol. 170, p. 842). Extract from the Chemiker Zeitung of May 16, 1925, giving a brief account of H. Schilling's method for the rapid estimation of iron and alumina in refractory materials.

Analysis of Fuel.—A. E. Best, *A Routine Apparatus for the Determination of Volatile Matter in Coal* (Fuel, Sept. 1925, p. 382). The apparatus consists of eight cylindrical crucibles with lids supported on a stand of silica plate. Eight 1-gramme samples can conveniently be heated during seven minutes at 900°C . in a gas or electric muffle. The gases from the distillation of the 8 grammes of coal are sufficient in volume to maintain a reducing atmosphere within the muffle.

P. Lebeau, *Gas Analysis* (Chaleur et Industrie, May 1925, No. 61, pp. 236–245). A very wide review of the subject in all its aspects.

H. R. Ambler and T. C. Sutton, *Absorption of Carbon Monoxide*.
I. Critical Comparison of Some Methods Employed in Gas Analysis.
II. Advantages of Using Hot Reagent (Analyst, 1925, vol. 50, pp. 167–174).

NOTICES OF RECENT BOOKS PRESENTED TO THE LIBRARY.

ADAM, A. T. "*Wire-Drawing and the Cold-Working of Steel.*" 4to, pp. 212, with 72 figures in the text. London, 1925: H. F. and G. Witherby. (Price 40s. net.)

Wire-drawing and wire-rolling are among those technical processes concerning which, for no apparent reason, a traditional secrecy has been observed, down to very recent times. Since the publication of "*Wire: its Manufacture and Uses*," by J. Bucknall Smith in 1891, no text-book dealing with wire and other products of cold-working processes has appeared, and such scanty information as exists on recent practice is scattered throughout the publications of various technical societies. The present volume deals with the aspects of wire-drawing and the effects of cold-working of iron and steel in wire-making and strip-rolling, from a definitely practical standpoint. The author explains the nature of wire and other cold-worked products, showing how their physical properties depend on the treatment to which the material is subjected. In view of the series of excellent articles recently published in *The Engineer* since published in book form, giving descriptive illustrations of the machinery and plant for wire-drawing, it has been thought unnecessary to devote much attention to the actual plant for carrying out the manufacturing operations, and the interest of the book centres chiefly on the discussion of the quality and preliminary treatment of the material, the extent of reduction by cold-work, heat treatment, and the relation of these matters to the properties of the finished product, to which full consideration is given. The book is intended not only for the metallurgist, but for the engineer and all those who are interested in the quality of the product of which they may be users, and—being the first authoritative work on the subject for many years—it supplies a long-felt want.

"*Anuario de Minería, Metalurgia, Electricidad y demás Industrias de España.*" (Anuario de la Industria Española.) 8vo, pp. 1029, published by the Revista Minera, Metalúrgica y de Ingeniería, under the direction of Don Adriano Contreras, Don Roman Oriol, and Don Luis Oriol. Twenty-fifth edition. Madrid, 1925: Sucesores de Rivadeneyra (S.A.).

This publication forms a complete directory of the Spanish mining and engineering industry. In the preliminary pages is given a list of Departmental Authorities in Spain concerned with the development of transport, agriculture, mining, and manufacturing industries of Spain. Furthermore, the book contains a directory of all learned societies, consulting engineers of every branch, mining companies, manufacturers of iron, steel, and other metals, the chemical industry, engineering and shipbuilding, and allied industries. The whole forms an indispensable work of reference to those engaged in commerce with Spain and its dependencies.

HERMANN, H. "*Bau und Betrieb moderner Konverterstahlwerke und Kleinbessemerieen.*" 8vo, pp. 251, with 217 figures in the text. Halle (Saale), 1925: Wilhelm Knapp.

The earlier book by the same author on "*Modern Open-Hearth Steel Works*" met with so good a reception, not only in Germany but in the

English-speaking countries, that the author was encouraged to produce another book dealing with up-to-date practice in the manufacture of steel by the Bessemer process. Notwithstanding prognostications as to the supersession within a measurable distance of time of the Bessemer acid and basic (Thomas) process by the open-hearth process, it is certain that on the Continent of Europe and in America the Bessemer process will long continue to hold its own on account of its paramount advantage of being able to produce a larger quantity of steel per unit of area and at a lower cost than has hitherto been possible by any other process. Moreover, this advantage is likely to be enhanced by the increasing price of scrap and fuel, neither of which raw materials play an important part in the Bessemer process. The chemical and metallurgical operations in both the acid and basic Bessemer process are fully discussed, and all the plant and machinery necessary for the efficient carrying out of the operations are described and illustrated. A considerable portion of the work is devoted to a discussion of the development of the small converter for use in steel foundries. The small converter as applied to this purpose has not proved as economical as the open-hearth furnace, on account of the great oxidation losses, but this notwithstanding, the use of small converters has continued to spread, particularly in Germany, for the reason that the installation of a small converter in any ordinary iron foundry is a much more simple matter than the construction of an open-hearth furnace. In fact, any engineering works with a cast iron foundry attached can supply its own requirements in the matter of steel castings by installing a small converter and enlarging the capacity of the blowing plant if necessary. A complete account of practice in the production of steel castings in the small converter is included in the book.

The author's historical accuracy is at fault upon one point. In referring to the first publication by Bessemer of his invention, the author ascribes to the Iron and Steel Institute, instead of to the British Association, the honour of having received, in 1855, the first report of Bessemer's epoch-making discovery. The actual delivery of the paper was made on August 16, 1856, to the latter body, the Iron and Steel Institute not having been founded until thirteen years later.

HEYN, E. "*Physical Metallography.*" 8vo, pp. 440. Translated from the German and somewhat enlarged by Marcus A. Grossmann. 1925. New York: John Wiley & Sons, Inc. London: Chapman & Hall, Ltd. (Price 30s.)

This translation into English of Professor Heyn's well-known standard work on metallography is highly welcome, since it renders more easily accessible to English-speaking metallurgists the work of that eminent authority, the late Professor Heyn. A thorough study of metallography involves a great diversity of knowledge, and the metallographer of to-day is no longer merely a microscopist, but requires to be a highly trained physicist and physical chemist. The study of metals and alloys has been entirely lifted out of the realm of pure empiricism to which it had previously been confined, and has now developed into a distinct science, whose roots extend into many different related sciences. The work discusses in clear and simple language the phenomena of the freezing and cooling of alloys, their transformations, the methods for determining the equilibrium diagrams, the structure of metals and alloys, the properties of strength and hardness, metallic substances and their combinations with gases, the phenomena of shrinkage and magnetic and electric properties of metals and their alloys. A new chapter on iron and steel has been included, with a brief survey of current theoretical conceptions, and a discussion of the types of alloy steel which are in general use to-day.

"*Hütte: Des Ingenieurs Taschenbuch.*" 8vo, pp. 1080. Volume I. Published by the Akademische Verein Hütte E.V., Berlin. Twenty-fifth revised edition, with numerous figures in the text. Berlin, 1925: Wilhelm Ernst & Sohn. (Price 13s. 6d. cloth bound; 16s. calf bound.)

The first edition of this important publication appeared in 1857, and with the present twenty-fifth edition the work may be said to have achieved its jubilee. In addition to the experts who assisted in the compilation of the former editions, a number of new specialists have been brought into collaboration, and with their assistance the pocket-book has been completely revised and brought up to date, so as to include notes on the progress of applied science and the engineering industry in all countries.

The following are the principal sections of the book and names of the respective authorities who have compiled the information: I. Mathematics: revised and enlarged by Professor Rothe. II. Mechanics: completely revised and rewritten by Professor Ludwig Föppl, Professor Marx, Professor Weber, Dr. Náday, Dr. Siebel, and Dr. Betz. III. Technical Physics: this section, covering the laws of vibration, acoustics, and optics, was edited by Dr. Hahnemann, Dr. Hecht, Professor Hort, Dr. H. Schulz, and Dr. E. Schmidt. IV. Heat. V. Strength of Materials. These last-named sections have been dealt with by Privy Councillor Mollier and Privy Councillor Laskus, who were responsible for the same sections in the previous editions. VI. Properties of Materials, Metals, Building Stone, Cement, Refractories, Fuel, &c. The sub-section on Non-Ferrous Metals has been greatly enlarged, and a number of new standards and formulæ have been included. The collaborators for this section are Dr. Aufhäuser, Professor Burchartz, Professor Hanemann, Dr. Hilliger, Professor Klut, Professor Maass, Dr. Obermüller, Dr. Proske, Dr. Rackwitz, Dr. E. H. Schulz, Dr. Siebe, Dr. Stamer, and Dr. Tepohl. VII. and VIII. Metrology, Geodesy, and Practical Geometry are now likewise incorporated in the first volume, and the material has been compiled by Professor Gramberg and Professor Hohenner. Reference to foreign technical literature has been greatly facilitated by the addition of numerous tables of conversion for all branches of technology, which have been calculated and compiled by Engineer Ludloff. The arrangement of the whole was in the hands of Dr. Sinner, who conducted the correspondence and collated all the material.

The book is the companion volume to the "Mining Engineers' Pocket Book" and "Metallurgists' Pocket Book," issued respectively in 1923 and 1924. Like them it contains a vast store of information based upon experience gained in actual practice, and constitutes the most useful work of reference to all engaged in any branch of engineering work.

ZERETELI, DATICO. "*Manganese Ore, with Special Reference to Georgian Ore.*" 8vo, pp. 136, with maps and diagrams. London, 1925: J. Davy & Sons, Ltd. (Price 8s. 6d.)

As indicated by the title, this work deals generally with the manganese ore industry, with particular reference to the present position of the trade in Caucasian manganese ore. A discussion of the uses of manganese ore is followed by a general review of the position of the world market before, during, and after the war. The world's sources of manganese ore are enumerated, with notes on the character and composition of the ores and statistics indicating the present state of development in the exploitation and use of manganese. A comprehensive survey of the manganese industry of Georgia is presented, with descriptions of the ore deposits, statistics of output, the number of mines, methods of working, means of transportation

of the ore to the ports of shipment, and other useful information. A number of interesting notes are given concerning the economic position of the manganese industry, and the manner in which regular supplies to the various iron-producing countries were affected by the war and the post-war conditions. The statistical information concerning production and imports for all the countries is very complete.

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